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**MOLECULAR BEAM EPITAXIAL
SYSTEM**

**SHANTHI N. IYER, WARD J. COLLIS
AND JIE LI**

FINAL REPORT

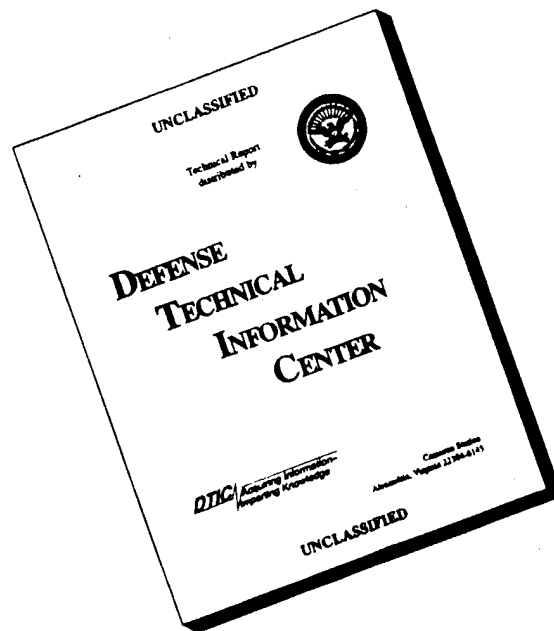
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ABSTRACT

During the period of this research grant, two major equipments Molecular Beam Epitaxy (MBE) and X-ray Diffractometer systems were ordered and installed. EPI 930 MBE system that can handle wafers upto 3" substrates has been installed. The system is modular, comprising of a growth chamber, a buffer chamber, and an introduction chamber which are connected through gate valves. The growth chamber is a nine source chamber with full beam monitoring facilities, such as mass spectrometer, ionization gauge and structural monitoring facilities such as RHEED system. The system has been specially designed with optical ports for ellipsometry, ports at grazing incidence to the substrate for in situ desorption measurements, numerous small optical ports near the source flange for the individual flux measurements, and an optical port on the substrate manipulator to measure the substrate temperature from the back of the substrate. The system has the necessary safety features namely, safety interlock system, back up power supply for the group III cells. A closed loop liquid nitrogen system has been installed for the liquid nitrogen transfer to the MBE cryopanel. The growth system is automated by the Molly software package.

A Bede 200/D³ High Resolution x-ray diffractometer system has been installed. The system has a resolution of 12 arc seconds and is computer software controlled.

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Project Title: MOLECULAR BEAM EPITAXIAL SYSTEM

This is a final technical report describing the research activities of the above AFOSR research grant. The one year grant period began on Oct. 21, 1993 and was extended on a no-cost basis for approximately ten months up to Aug. 14, 1995. This program involved the expansion of our research infrastructure on semiconductor materials growth facilities by adding Molecular Beam Epitaxial (MBE) system to the existing Liquid Phase Electroepitaxial (LPEE) system. This program involved the effort of two faculty members, one Research Associate and one MSEE student. Over this entire grant period, the suggestions from the technical monitor, Dr. Gernot Pomrenke were extremely helpful. Budget revisions were made to purchase X-ray diffractometer system as some dollar amount was saved from the budgeted amount for MBE. Speedy approval from the technical monitor and the agency is greatly appreciated which allowed us to expand our characterization capability. Hence the tasks during this period could be categorized on the description of these two equipments installed in the laboratory.

- I. MBE system: Description, monitoring and in-situ characterization techniques, and the acceptance test**
- II. X-ray diffractometer system : Selection and installation of the system**
The following sections detail the various technical accomplishments.

I INTRODUCTION

Molecular beam epitaxy (MBE) is a versatile technique for growing thin epitaxial structures made of semiconductors, metals or insulators. What distinguishes MBE from previous deposition technique is its significantly more precise control of the beam fluxes and growth conditions. Because of vacuum deposition, MBE growth is carried out under conditions far from thermodynamic equilibrium and is governed mainly by the kinetics of the surface processes occurring when the impinging beam react with the outermost atomic layers of the substrate crystal. This is in contrast to other epitaxial growth techniques, such as liquid phase epitaxy (LPE) (this technique has been the only growth technique in our laboratory for the growth of III-V semiconductors so far) or vapor phase epitaxy, which proceed under conditions near thermodynamic equilibrium and are most frequently controlled by diffusion processes occurring in the crystallizing phase surrounding the substrate crystal. MOCVD offers the most competitive alternative to MBE of the epitaxial film processes, while, still inferior in terms of absolute thickness, doping control and in-situ monitoring. Recent progresses in low pressure MOCVD and metal-organic MBE (MOMBE) is bringing both process regimes closer together, however, one serious disadvantage of MOCVD is the toxicity of the gases required. In addition, some of the less toxic gases are pyrophoric. Expensive safety precautions are required for operating personnel and to reduce environmental liabilities and these factors are of primary concern especially in an university environment.

Historically, most of the devices were initially conceived in MBE systems which were subsequently fabricated by other techniques. MBE has been well proven to favor epitaxial growth

of metastable phase materials such as CdSe on GaAs or on ZnTe. Further, MBE has a unique advantage. Being realized in an ultrahigh vacuum environment, it may be controlled in situ by surface sensitive diagnostic methods such as reflection high energy electron diffraction (RHEED), ellipsometry, Auger Electron spectroscopy (AES). More and more techniques are being added into this application, such as desorption mass spectrometer, atomic force microscope, x-ray diffraction, Raman scattering, laser reflection and photoluminescence/photoreflectance measurements on the back side of the substrate wafer. These powerful facilities for in-situ growth control eliminate much of the guesswork in MBE, and during the last decade have allowed the fabrication of high quality heterostructures with designed potential profiles and impurity distributions with a dimensional control close to interatomic spacing with virtually defect-free interfaces in a lattice matched case. Thus, it offers the possibility of growing semiconductor materials with unique properties and a wide variety of hitherto impossible and unimagined devices.

Hence, MBE was our choice for the growth technique for the growth of Sb based alloy system, which are known to be the most difficult material system to grow in III-V semiconductor family in terms of crystal quality.

II. MBE SYSTEM

A.1 Laboratory Facilities

The existing liquid phase electro-epitaxial (LPEE) laboratory has been renovated for setting up the MBE equipment and LPEE system has been moved to an adjacent room. Modifications were made in the plumbing and electrical lines in the MBE laboratory to facilitate the installation of the MBE system. A new six feet fume hood, Microvoid Model FH-21, that includes a heated ultrasonic tank with its accommodation unit, and a de-ionized water handspray was installed. Funds towards purchase of this equipment came from the College of Engineering. Following set ups were installed for the operation of the MBE system.

(1) LN₂ System: A Vacuum Barrier LN₂ transfer system has been set up in the MBE lab which includes six outlet phase separator, mechanical and diffusion pump assembly and vacuum pumping lines for the Vacuum Barrier system, LN₂ transfer lines and N₂ gas vent lines, safety valve, vacuum gauge, system monitor and controller. Four of the six outlets from the phase separator are used: one pair for supply and return from the LN₂ panel in the MBE source flange and the other pair for the LN₂ shroud. A 1500 gallon capacity liquid nitrogen storage tank placed on a 18" thick concrete pad constructed primarily for this purpose, outside the laboratory provides the supply.

(2) Nitrogen Gas System: The pure nitrogen gas required to drive all the pneumatic gate valves and shutter systems is obtained from the liquid nitrogen tank, which regulates the pressure at 80 psi. Additional fine filters are also added in the line.

(3) DI Water System: DI water system from Millipore Co. with more than 18 M-ohm resistivity at room temperature for the deionized water supply has been installed.

A.2 Description of the Equipment

Currently in the MBE market, there are four principle manufacturers, Riber, Fisons, DCA and EPI. Technical sales representative from each of these companies were invited to do a detailed presentation on their system before the bidding. Bidding for the MBE equipment with special features desirable for the growth of Sb compounds was submitted to Raleigh-State Office in the beginning of May 1994. A copy of the papers for bidding sent by N.C. State office at Raleigh is included in Appendix A. Only three vendors EPI, Fisons and DCA bid for the system. Riber for unknown reason did not bid. The bidding process was completed by the end of September, 1994. EPI's MBE system won the bid. There was a delay of approximately four months in the delivery of the system and the EPI 930 nine source MBE system was delivered on June 21, 1995 and was installed during the first week of July.

Keeping in view the specific application of MBE system towards the growth of Sb based compounds, MBE system from EPI(Model #930, see Fig.1a) with the following features have been installed in the laboratory.

(1) Introduction Chamber: This chamber allows rapid loading and unloading from the MBE machine. This chamber comprises of Molybdenum holders for 3 in. diameter substrates with six substrates at a time can be loaded onto a "trolley" to move the substrates from the entry chamber to the buffer chamber via magnetic coupling, viton sealed rapid access door for loading, a vent valve, 200°C internal bakeout, vacuum gauges and their control from atmosphere to high vacuum, a roughing system that includes Balzers wide range 170 liters per second magnetic bearing oil-free turbo and molecular-drag pumps, and effusion cell baking fixture bakeable to 1600° C for one cell at a time.

(2) Buffer Chamber: This chamber is used for substrate storage and to vacuum isolate the growth chamber. This has an independent ultra high vacuum (UHV) system comprising of 220 l/s triode ion pump with ion gauge and controllers, second trolley/cassette for substrate storage, a blank port for system expansion, and a blank port for adding substrate heating stage in future.

(3) Growth Chamber: This chamber is the most important stage in the MBE system. It is a tilted chamber system to facilitate loading of sources in large quantity in effusion cells. This chamber consists of ports for nine effusion sources with individual beam shutters positioned to interrupt the beams between the sources and the substrate (see Fig. 1b). In addition, there is a main or substrate shutter that allows the nine beams to be interrupted at once.

A radial vane baffle, or source shroud, allows cooling of the entire assembly by liquid nitrogen. The shroud is designed to isolate each heated source both thermally and optically - preventing radiation from affecting the temperature setting of adjacent sources, and insuring source integrity and cleanliness by intercepting any stray material. A separate cryopanel is provided surrounding the substrate growth stage, that enhances vacuum purity for improved material growth, and acts as a heat "sink" to stabilize the thermal environment of the growth chamber.

The substrate manipulator provides continuous sample azimuthal rotation along the axis of the manipulator. The substrate heating stage which can go up to 1000°C is water cooled. The manipulator incorporates heating element in PBN enclosure that heats the back of the substrate and Ta heat shielding that surrounds the outside perimeter of the substrate, so that radiative heat

loss does not cause non-uniform heating at the edge of the substrate. The manipulator has an optical access at the back side of In-free mounted substrate. This option will allow in future the use of CI optical temperature contactless measurement, to provide better control of growth temperature.

Cell to substrate distance is 8.78" with the substrate electrically isolated from the growth chamber. Electrical isolation of the substrate for biasing the substrate is desirable for the potential growth of GaN films where biasing is reported to assist in improving the quality of the grown epilayers.

There are ports for mounting the monitoring and analytical facilities such as, reflection high energy electron diffraction (RHEED) gun, phosphor screen, ion gauge beam flux monitor residual gas Analyzer (RGA) and pyrometer.

A pumping "sump" accommodates a 440 l/s Ti-ball sublimation pump with two additional ports for future UHV use. Rough pumping to the chamber is achieved using the Balzers turbo molecular pump used in the introduction chamber, which is connected to the chamber through an all metal valve

(4) Optical Ports: More and more MBE systems are adopting optical techniques as a means of growth monitor and control. Keeping up with the current trend, several optical techniques have been included in our MBE system. The system has a pair of ellipsometry port of 2.7" CF flange positioned at 73° with respect to the substrate normal. This will allow in situ monitoring of film thickness, alloy refractive index and compositions, vital for the growth control and investigation of multilayered heterostructures.

One pair of ports are provided at a grazing incidence to the substrate for the in situ source beam flux measurement and laser reflection surface monitoring. A pair of 1.33" CF optical ports has also been provided for each of the source cells in a position perpendicular to its corresponding source flux. These ports have been specially designed so that it would not affect the integrity of the vacuum in the growth chamber. This technique would provide an excellent in-situ control of the individual fluxes, in particular, the group III fluxes.

In addition, there are 600 ° C heatable IR pyrometer optical port , standard ports to view almost all the effusion sources and the entire transfer system .

(5) Source Cells: All cells except the ones for doping have large loading capacity of 125 cc for longer operation time before source reloading. All crucibles adopted are conical to produce highly uniform beam flux densities over an area of 3" diameter at the substrate. Low flux transient group-III cells of conical insert effusion cells for In and Ga sources are expected to reduce significantly the flux transient, essential to improve the composition control and to minimize the composition gradient at the interfaces. The crucibles for the Be & Te dopants are of 5cc capacity.

Effusion cell of group-V element As is a valved cracker source of 500 cc capacity. Effusion cell of the other group V element Sb is a cracker source, though as per the original quote the vendor was to provide a valved cracker source. However, they were not successful in manufacturing one. The use of crackers will allow the use of lower substrate temperatures where the temperature sensitivity of the cracked species is relatively less. Further, the valve in As cracker would permit abrupt changes in As fluxes, providing precise control of this species crucial for the successful growth of the quaternary (GaInAsSb) system and heterostructures.

(6) Back Up Power Supply: Amongst all the sources, Al and Ga cell crucible are more prone to breaking when rapidly cooled. This is due to the difference in thermal coefficients of the

above solid sources and PBN crucible. The thermal coefficients of expansion (TCE) of solid Al and PBN crucibles are different, being $23 \times 10^{-6} / ^\circ\text{C}$ and $3 \times 10^{-6} / ^\circ\text{C}$, respectively, and also solid and liquid Ga exhibit different densities of 5.904 g/cm^3 and 6.095 g/cm^3 , respectively. Hence most often the crucibles are known to break when the phase changes from solid to liquid or vice versa. In order to protect the MBE furnaces, an inexpensive back-up power supply system has been designed in the laboratory, that provides power directly to the Al and Ga source cells, to maintain their elevated temperature in the event of power failure. The back-up power supply includes 12 volts batteries, battery chargers, relays, diodes, 3 way switches and current adjusters as shown in Fig. 2. It has been designed such that in the event of power loss, the backup provides power to maintain Al furnace temperature above 670°C and Ga furnace above 40°C .

(7) System Design: The system is modular, allowing for easy incorporation of additional chambers and system if the need arises. The system design is such that it could be made compatible with gas source system infrastructure in future.

(8) Automated Control System: The MBE system operation and growth processes are computer controlled. The control software "Molly" provides control functions for deposition recipe generation and editing while running a growth, real time system status monitoring during growth, setup of system parameters (PID parameters, shutter speed, error levels, vacuum gauge parameters etc.), direct control of system conditions namely, all cell and substrate temperature settings, time sequencing of shutter operation, valve position of valved crackers, ion gauge control, flux monitor position and readout, substrate rotation, and gate valve positions.

A.3 Other MBE Monitoring and Analytical Facilities

(1) IR Pyrometer: An infrared pyrometer has been installed on the central optical port of the source flange of the MBE machine with a special installation frame for in situ substrate surface temperature monitoring. The pyrometer is *Modline Plus* model of V series made by IRCON, Inc. that has a 400 to 1000°C working temperature range, D/20 optical resolution and high sensitivity. It operates in a narrow band of spectral region from 0.91 to 0.97 microns and thus it is opaque to both GaAs and GaSb substrate wafers, thus eliminating the IR signal from the substrate heater.

The view port for the pyrometer is bakeable to 600°C as opposed to the conventional view port (which can withstand temperatures only up to 250°C). This would minimize the clouding of the viewport by the high vapor pressure species namely, As and thus would allow a better control and reproducibility of the substrate temperature measurements.

The ion gauge beam flux monitor is mounted on a linear motion feed-through on a separate $6''/150 \text{ mm}$ CF flange. During the measurements, the gauge is positioned at the focal point of the effusion cell array and is in full view of all nine effusion cells and the substrate is completely shielded from the flux beam by a plate behind the gauge.

(2) Mass Spectrometer: The HAL/3F PIC Quadruple Mass Spectrometer of Hiden Analytical with 1 - 510 amu mass range, has been installed in one of the nine MBE source ports. This is an ultrahigh sensitive instrument with 10^{-15} torr detection level with a fast pulse counting detector that greatly enhances signal/noise ratio.

Due to the high cost of GaSb wafers, sample dimensions used for the growth will be smaller than $1''$ in diameter. Hence the beam has to be focused to less than half inch diameter at the center of the Mo block substrate. Therefore, a special aperture and an angle adjustment bellow assembly have been designed to align the RGA head with the substrate. The entire RGA

data acquisition and processing will be computerized. This would allow investigation of Sb and As desorption from the growth surface to study the growth kinetics and would provide an additional information on the growth mechanism.

(3) RHEED: Fison's LEG110 RHEED gun and controller has been installed in the RHEED port. The unique features of this RHEED system are: smallest (50 μm) spot size which produces sharp well defined pattern, electron energy range of 0-15 KeV with low electron beam, electrostatic lens focusing that does not produce stray magnetic field and a very low beam drift that is expected to stabilize the beam at high intensities. However, this is the only system that had never functioned, as there was quite a few problems and has been sent back to the vendor.

Considering the fact that the materials used in our system, As and Sb, have high vapor pressures, the RHEED screen port is load-locked to the main chamber with a gate valve, to facilitate changing of the screen without breaking the vacuum of the growth chamber.

A.4 MBE System Acceptance Test

In order to evaluate the quality of MBE system, we established a complete test procedures which were to be carried out into two stages.

The first stage consisted of mechanical testing of the system before loading the source and only on completion of these testings, major portion of the payment (90 %) towards the cost of the system to be made. The rest of the 10 % of the payment to be made after the completion of the second set of test described later. The mechanical tests include: ultimate vacuum 5×10^{-11} , 5×10^{-10} and 5×10^{-8} torr in growth, buffer and introduction chamber, respectively; growth chamber vacuum pump down speed; 3" substrate temperature uniformity $\pm 2^\circ\text{C}$ and stability $\pm 0.2^\circ\text{C}$ at 600°C ; substrate temperature reproducibility $\pm 3^\circ\text{C}$ with respect to Mo block temperature variation; furnace temperature controller stability $\pm 0.1^\circ\text{C}$ and wobble of the substrate $< 0.1^\circ$ while rotating;

The second set of tests on the material quality grown in the system include the following: flux stability $\pm 1\%$; As cracker and Sb valved cracker temperature stability $\pm 0.2^\circ\text{C}$ and their flux stability less than 2 % and valve controlled flux reproducibility better than 4 %; group-III source flux reproducibility $< 2\%$ and shutter related flux transient $< 1\%$ for Ga and In, $< 3\%$ for Al; grown film homogeneity $\pm 1\%$; experiments to check the individual source shutter and the main shutter performance; grown undoped GaAs layers with $n < 5 \times 10^{14} \text{ cm}^{-3}$ and 77 K Hall mobility $> 70,000 \text{ cm}^2/\text{Vs}$ with oval defect density $< 200 \text{ cm}^{-2}$; the compositional uniformity of grown GaAlAs alloy better than $\pm 1.5\%$; background carrier concentration of directly grown GaSb on GaAs(100) $< 1 \times 10^{16} / \text{cm}^3$ with room temperature electron mobility of $6000 \text{ cm}^2/\text{Vs}$.

There were major problems in meeting many of the specifications outlined in the bid. A few of these were: the ultimate vacuum, wobble, substrate temperature reproducibility, malfunction of flux monitor system, noisy substrate rotation, misaligned substrate transfer system, numerous leaks in water and air systems, malfunction of the overheating alarm interlock of baking system, automatic rough pumping sequence of the introduction chamber and few problems with the Molly software.

Through cooperative work on the both the sides, great progress has been made. Most of the specifications for the 90% payment has been met. However, it took almost five months of intensive effort on both the sides. Though many of the specifications such as wobble of the

substrate are close to the specifications in the bid though not exact, we have decided to accept the close specifications due to the great amount of time that's invested on it. Detailed results on the testing prior to the source loading are described below.

(1) Vacuum: The system was initially baked at 200 °C and cooled. The vacuum attained in the system was 4×10^{-10} torr. Later the system was again baked for another fifteen days which did not make any change in the ultimate vacuum. The predominant peaks in the RGA spectra corresponded to hydrogen, water, nitrogen and a small amount of oxygen. Several leaks were detected, predominant ones were the metal valve, and couple of 1.33" mini-flanges, one on the venting port and other one was located below the RHEED screen. After changing the gaskets, the system was pumped down to 10^{-9} torr and baked at 180 °C for two days. Hydrogen peak was still predominant with small amount of water, nitrogen and CO₂. Oxygen peak was not observed even under the high sensitivity set up, indicating the absence of any leak. The vacuum attained was 1×10^{-10} torr. When all cells were heated to 500 °C with the substrate stage at 700 °C and the main chamber sublimation pump "on" for one day, the system vacuum reached 5×10^{-11} torr. On lowering down all the above temperatures to room temperature, the vacuum improved to 3.6×10^{-11} torr meeting the ultimate vacuum criterion specified in the bidding.

(2) Wobble: Initially tests on several Mo blocks and 3" silicon wafer with manual rotation exhibited wobble in the range of 0.6 to 0.7°. The substrate manipulator was sent to EPI and the substrate stage was modified. Spinner was changed from Mo sheet to PBN and the spinner was pulled closer to the heating filament. Also the magnetic handle was modified from three to one pin with the magnetic handle changing from free-standing to fixed position. The wobble on Mo blocks reduced to 0.31° at room temperature and on increasing the temperature to 700 °C, the wobble increased to 0.36°. The set up used for testing the wobble is as shown in Fig. 3. A He-Neon laser beam placed in front of one of the ellipsometry port is incident on the Mo block. The deflection of the reflected light spot exiting from the other ellipsometry port of the growth chamber provides the measure of wobble.

(3) Substrate Holder Temperature Reproducibility: Substrate temperature reproducibility tests were done by cycling the heater between 700 °C and 350 °C. An In bonded molybdenum block onto the stage served as a non-transparent sample for pyrometer. Control and pyrometer temperatures were allowed to stabilize at each set-point for at least half an hour and data were taken to record the stage performance. Considerable variation in the substrate temperature was observed. This variation was in the range of 6 °C for the same Mo block. The temperature change between two Mo blocks was as high as 10 °C. So, the thermocouple stage of the substrate manipulator was modified by EPI. A radiation shield was removed as it was believed that this may have served as a point of asymmetry in the thermal profile of the heater assembly. The recent results indicate that though there is some improvement it is not stable for the first couple of hours. The temperature of the stage continuously decreases from 588 °C to 573 °C. However, the stage performed quite well, once it is initial conditioned and the repeatability was good within $\pm 1^\circ\text{C}$ as illustrated in Fig. 4. The temperature difference between the thermocouple reading and the pyrometer measurement is around 120 °C at the setting point of 700 °C Eurotherm temperature controller.

(4) Substrate Holder Temperature Stability: The substrate holder temperature was fully stabilized at 700 °C (more than one hour time stabilization), the substrate was manually rotated. Eurotherm temperature controller stabilization was within $\pm 0.1^\circ\text{C}$ at 700 °C. The variation in the pyrometer reading was within $\pm 5^\circ\text{C}$.

(5) Substrate Holder Lateral Uniformity: After the complete stabilization of the substrate temperature at 700 °C, the IR pyrometer was aimed at different locations on the Mo block of the substrate stage. The pyrometer measured temperature distribution is shown in Fig. 5. Substrate was not rotated during this measurement. Temperature variation across the Mo block was around 3 °C, at the setting point of 700 °C Eurotherm temperature controller.

(6) Source Cells Temperature Stability: All cell temperatures were stabilized at 500 °C \pm 0.2 °C with auto-tuning PID settings. As the sources are not loaded, the actual stability of the cells cannot be performed.

Very recently a potential problem associated with the safety interlock system of the MBE has been identified. The vacuum safety was designed to interlock the growth chamber with the introduction chamber ion pumps. The ion pump has an automatic safety shut down feature, namely, once the vacuum in the chamber drops down to below a certain value (around 10^{-6} Torr) the ion pump will shut off itself. Any shut off of the ion pump will immediately trigger the interlock system to shut off the electrical power for the substrate and effusion cells. However the problem arises when the power resumes, ion pump remains off, till it is turned on manually. The power supply to the cells and substrate remains disconnected. Further the return of the power will automatically disconnect the backup power supply. This problem associated with the interlock system has been notified to EPI. EPI is in the process of sending a new hardware and software package that would reset the temperature of all the cells and the substrate to an idling temperature.

III. X-RAY DIFFRACTOMETER SYSTEM

This is one of the important and standard characterization technique that has to be routinely carried out on MBE materials. This technique determines the epitaxial film crystalline quality, lattice constant and alloy compositions. Strain, interface smoothness and layer thickness of superlattice and quantum well materials can also be examined.

B.1 Laboratory Facilities

As there was not sufficient room in the MBE and optical characterization laboratories, another laboratory was identified. The electrical and water utilities were added to accommodate the system in that laboratory, which is currently being shared by one of the mechanical engineering faculty.

B.2 Description of the Equipment

A high resolution x-ray diffractometer system that has the capability of carrying out glancing incidence reflectivity, wide angle scan, high resolution rocking curve with Ω or $\theta/2\theta$ scans, x-ray topography, wafer mapping, which can be up-graded to high resolution triple axis system went for bidding on April 1995. A copy of the bidding papers on this equipment sent by the N.C. State office at Raleigh is included in Appendix B. Only one vendor North Eastern Analytical company responded.

A Bede 200/D³ high resolution x-ray diffraction system from the above company has been ordered. This automated high resolution x-ray diffraction system consists of 3 kW stable x-ray generator that utilizes Cu target. The collimator and monochromator consist of two crystal blocks of highly perfect silicon. Each block has two channels that are cut in such a way that either (220) or (400) reflections can be used. Either two or four bounces can be chosen depending on the resolution desired. The resolution of the first and second axes of the diffractometer is 0.5 arc second. The detector is an extended range x-ray scintillation counter tube with intrinsic background below 0.15 cps, linear dynamic range 6.5 decades with linear response range up to 400,000 cps. The system has the capability of measuring glancing incidence x-ray reflectivity, high resolution rocking curve with Ω or $\theta/2\theta$ scans and x-ray topography. In order to be upgradable to the triple axis system, it has the provision for the addition of a third channel cut crystal.

B.3 Current Status

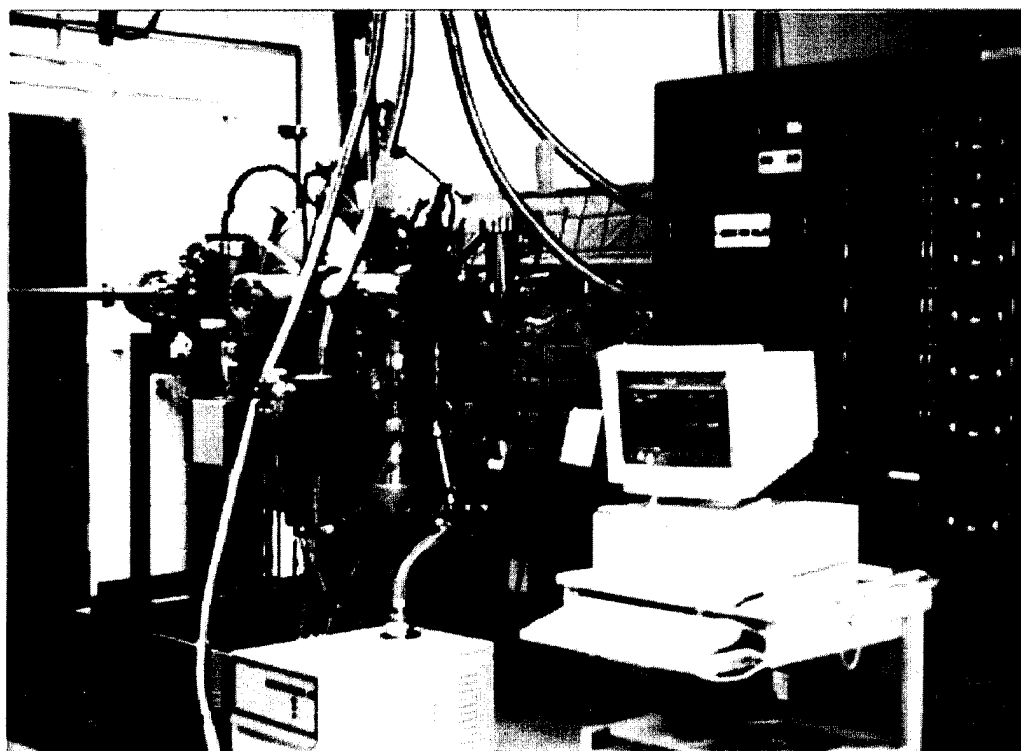
The first part, that includes x-ray machine enclosure, support frame and electric control system which were built in USA have been received and installed. There was a minor problem as the door dimensions were smaller than the width of the table and a modification of the x-ray machine frame was done to fit the door dimensions. Computer software and manuals which run the x-ray diffractometer have been received. The X-ray generator, which was originally scheduled to be delivered at the end of September was delayed and has been delivered and is currently being installed as this report is being written. A photograph of the system is shown in Fig. 6.

IV. CONCLUSIONS

EPI 930 Molecular beam epitaxial system has been installed for the growth of III-V semiconductor materials. The system is modular, comprising growth, buffer and introduction chambers. The growth chamber is a nine source chamber equipped with RHEED, RGA, ionization gauge and pyrometer. The system is designed with numerous optical ports to allow different in-situ optical measurements. Vacuum Barrier's phase separator has been installed for the LN₂ transfer to the cryopanel. The growth system is automated by the Molly software package. Number of safety features namely, safety interlock system, back up power supply for the group III cells have been designed into the system.

A Bede 200/D³ High Resolution x-ray diffractometer system has recently been installed. This system has a resolution of 12 arc sec. The laboratory is now well equipped with the state of the art growth technique, structural and optical characterization facilities for III-V semiconductor materials.

V. FIGURES



a)



b)

Fig. 1. a) EPI 930 MBE system and b) source flange.

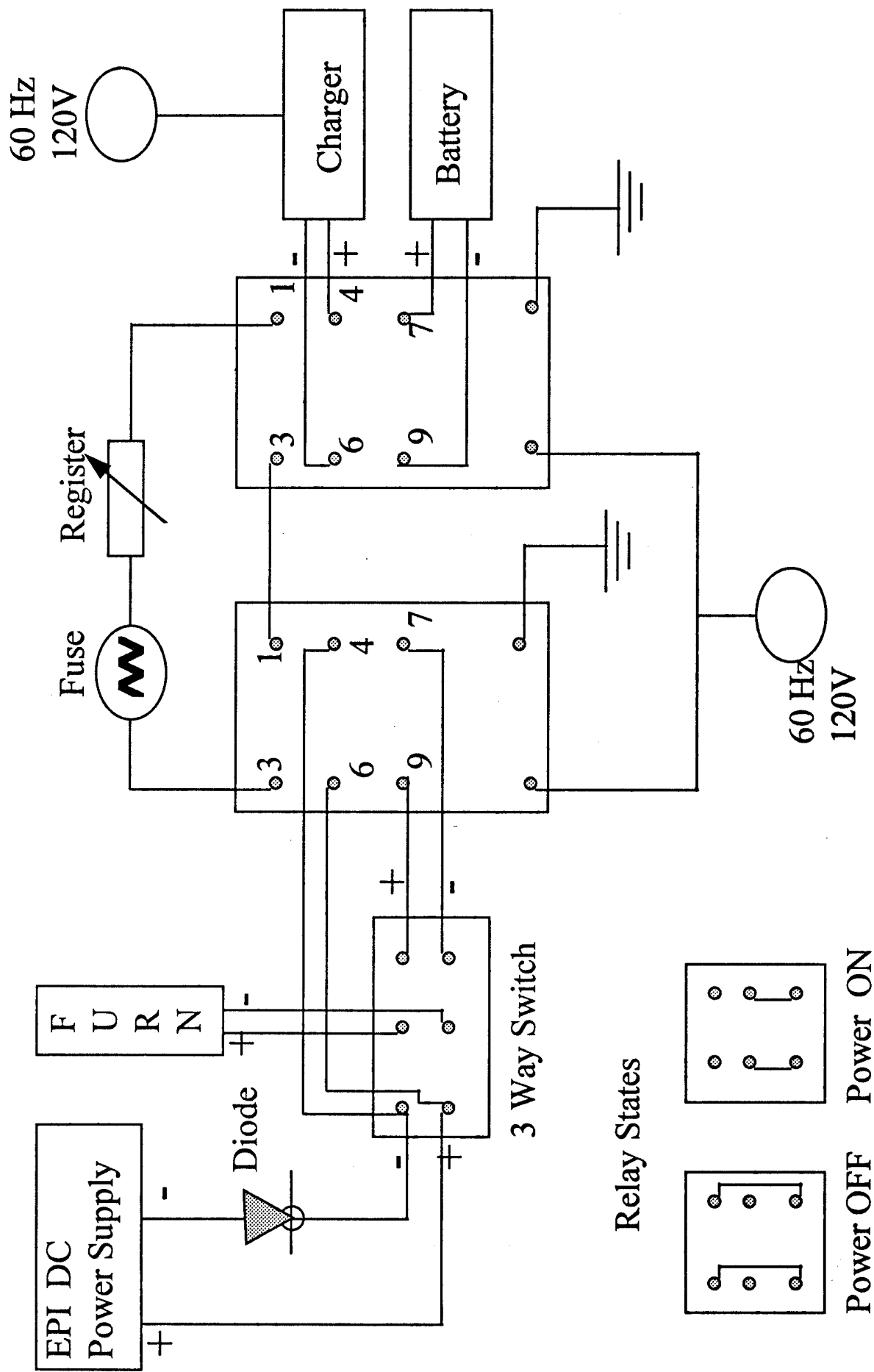


Fig. 2. Schematic diagram of the back up power supply for Ga and Al sources

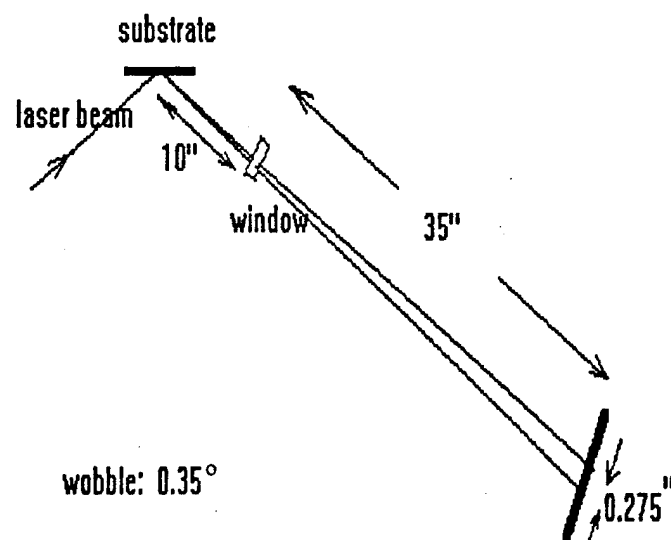


Fig. 3. Schematic representation of the experimental set up for the wobble test.

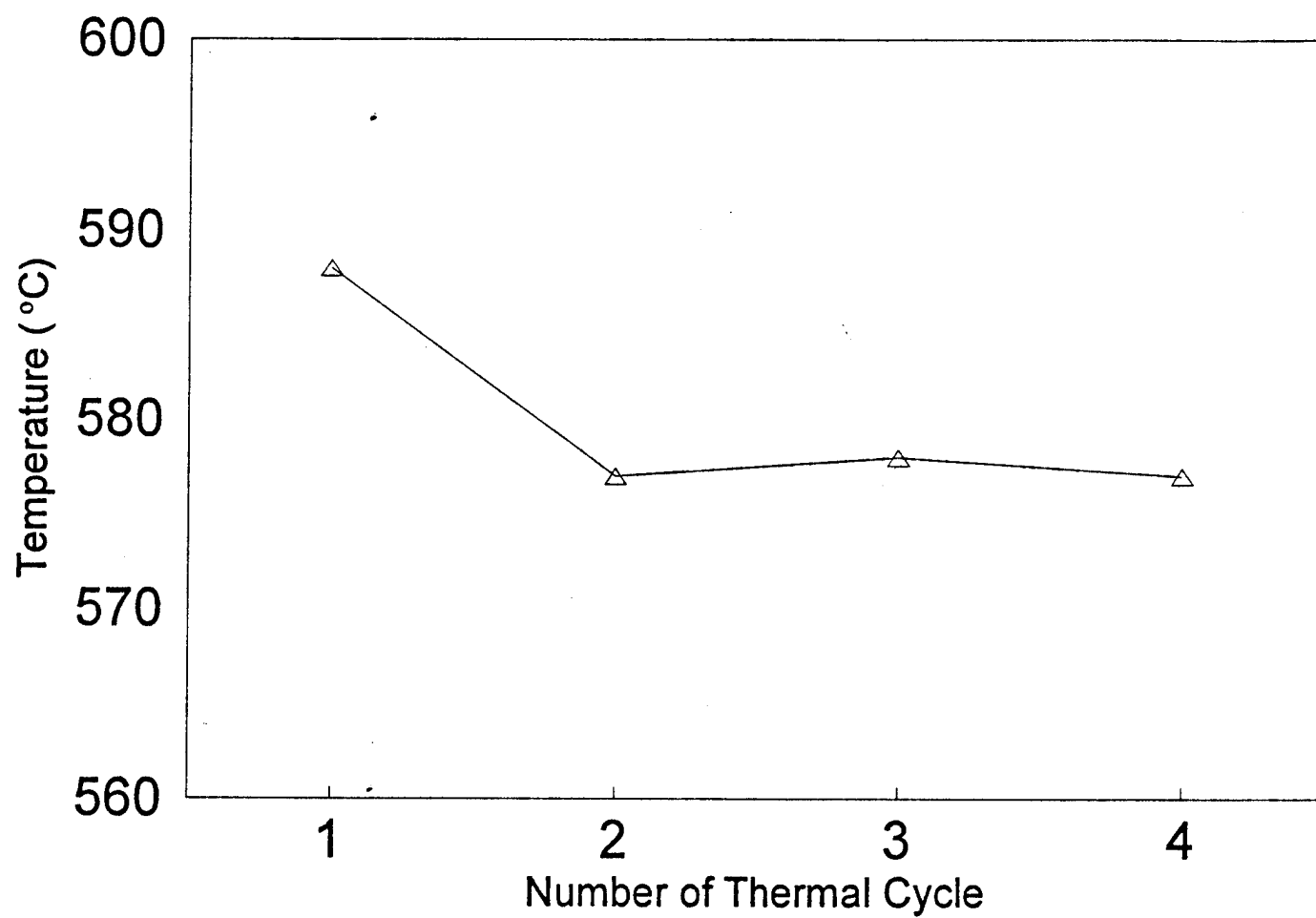


Fig. 4. Substrate holder temperature reproducibility after each thermal cycle ($700^{\circ}\text{C} \rightarrow 350^{\circ}\text{C} \rightarrow 700^{\circ}\text{C}$).

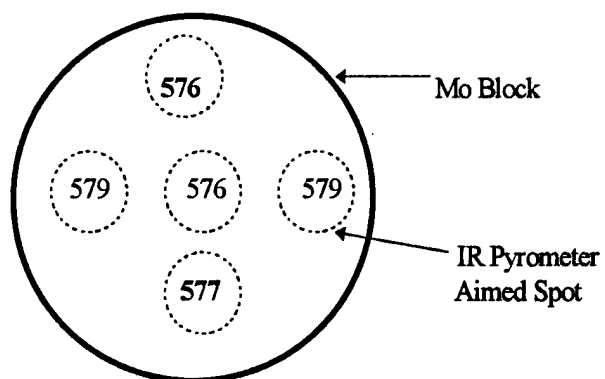


Fig. 5. Variation of the temperature at different points on the Mo block-substrate holder as measured by the pyrometer. Eurotherm temperature controller setting was at 700°C.

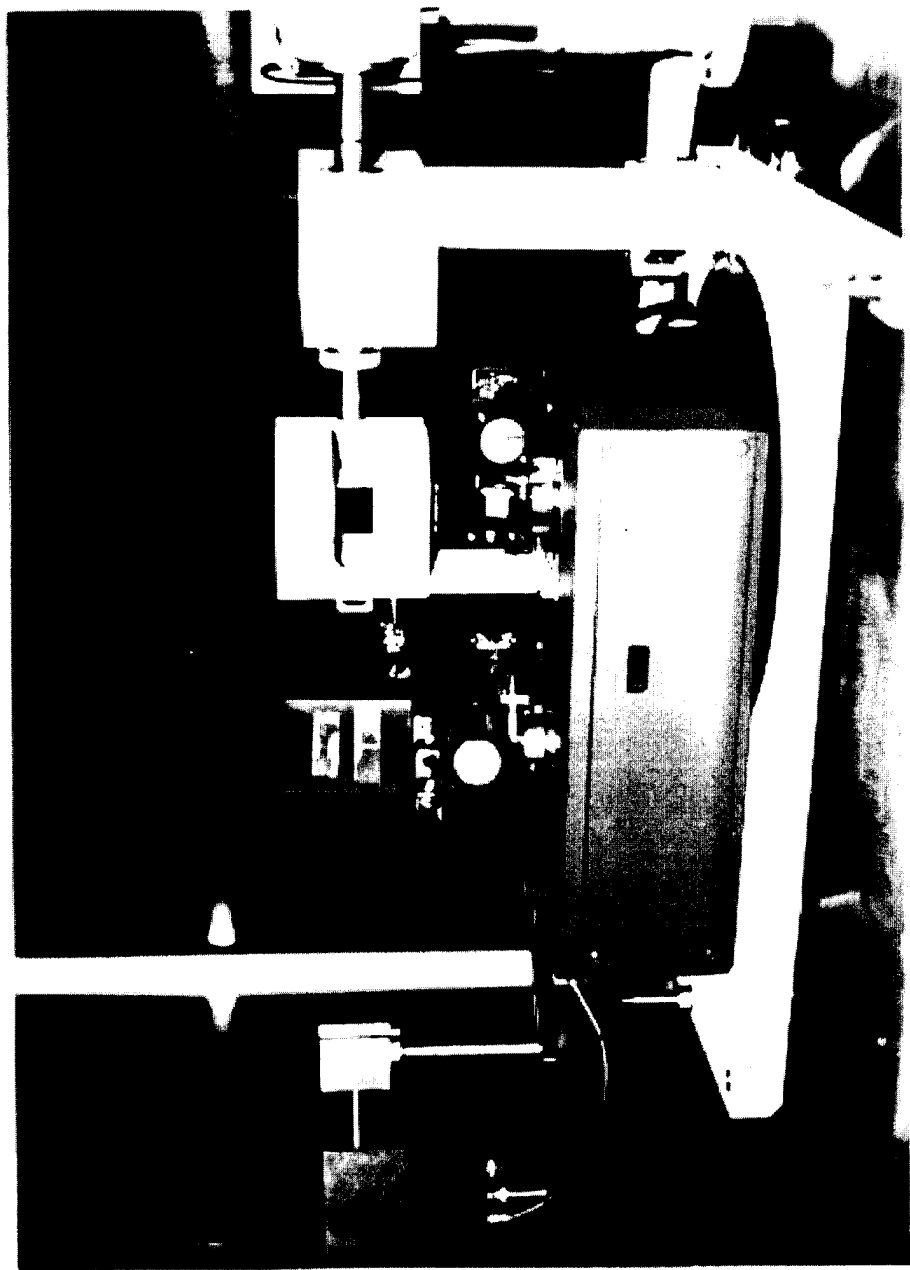


Fig. 6. Bede 200/D³ high resolution x-ray diffractometer system.

VI. PARTICIPATING SCIENTIFIC PERSONNEL AND REPORT SUBMITTED

Faculty

Dr. Shanthi Iyer, Associate Professor
Dr. Ward Collis, Associate Professor
Dr. Jie Li, Research Associate

Dr. Jie Li came from Emory University on a subcontract from another AFOSR research grant entitled "MBE Growth of GaInAsSb" (Grant No. F49620-93-1-0111DEF).

Graduate Student

Mr. Badri Mangalam, MSEE

Report Submitted

S. Iyer and W. Collis, "MBE System" Interim Report, Oct.1, 1993 - Sept. 30, 1994.

VII. APPENDICES

APPENDIX A

Invitations for bids on the MBE system

STATE OF NORTH CAROLINA
DEPARTMENT OF ADMINISTRATION
DIVISION OF PURCHASE AND CONTRACT
RALEIGH, NORTH CAROLINA
JULY 28, 1994

INVITATION FOR BIDS

RECEIVED

AUG 08 1994

PURCHASING
DEPT.

IMPORTANT: SHOW BID
NO. ON RETURN ENVELOPE

BID NUMBER:

404378

TO BE OPENED ON:

August 18, 1994

REQN: 03113

Molecular Beam Epitaxial System

Sealed bids, subject to the conditions made a part hereof, will be received at this office until 2 o'clock P.M., Thursday, August 18, 1994, and then publicly opened, for furnishing the supplies, materials and/or services, as described below, delivered in accordance with paragraph entitled 'TRANSPORTATION CHARGES.'

REFER INQUIRIES TO: Yvonne Lewis Holley
Asst. Purchasing Administrator

NAME OF BIDDER: _____

CITY AND STATE: _____

TELEPHONE NUMBER: (919) 733-6604

ZIP CODE: _____

MAILING LIST NUMBER:

493-77-62 This is a rebid of 404065

GENERAL: ALL PROPOSALS ARE SUBJECT TO THE PROVISIONS OF THE ATTACHED GENERAL CONTRACT TERMS AND CONDITIONS FORM R-1, EXCEPT PARAGRAPH 17. ALL "INVITATION FOR BIDS" RESPONSES WILL BE CONTROLLED BY THE TERMS AND CONDITIONS INCLUDED BY THE STATE. TERMS AND CONDITIONS INCLUDED AS A PART OF PUBLISHED PRICE LISTS, CATALOGS AND/OR OTHER DOCUMENTS AS A PART OF THE BID RESPONSES ARE WAIVED AND WILL HAVE NO EFFECT EITHER ON THE BID, OR ANY CONTRACT WHICH MAY BE AWARDED AS A RESULT OF THIS INVITATION. THE ATTACHMENT OF ANY OTHER TERMS AND CONDITIONS BY THE BIDDER MAY BE GROUNDS FOR THE REJECTION OF THAT BID.

BIDDER SPECIFICALLY AGREES TO THE CONDITIONS SET FORTH IN THIS PARAGRAPH BY SIGNATURE OF THE "EXECUTION OF BID" CONTAINED HEREIN.

PURSUANT TO G.S. 143-48 AND EXECUTIVE ORDER NO. 77, THE STATE INVITES AND ENCOURAGES PARTICIPATION IN THIS PROCUREMENT BY BUSINESSES OWNED BY MINORITIES, WOMEN AND THE DISABLED.

NO BID INFORMATION

If you desire to "no bid" this requirement, provide the information requested below, sign and return only this page, check appropriate box(es)

☐ NO BID, ALL ITEMS ☐ REMOVE FROM MAILING LIST FOR THIS COMMODITY ONLY

Reason(s) for no bid: _____

Bidder: _____

Signature: _____ Date: _____

FACSIMILE (FAX) BIDS: BIDS AND/OR ADDENDA SUBMITTED VIA FACSIMILE (FAX) MACHINE IN RESPONSE TO THIS INVITATION FOR BIDS WILL NOT BE ACCEPTABLE

BIDS ARE SUBJECT TO REJECTION UNLESS SUBMITTED ON THIS FORM

BID NO. 404378

BIDDER :

TABULATIONS: Bid tabulations and award information can be obtained by calling (919) 733-4528. Tabulations will be available upon request no earlier than 9:00 AM on the first working day following the date of bid opening. In accordance with the North Carolina Administrative Code, Section 5B.0313, requests for detailed or written tabulations cannot be honored.

USER: N.C. A & T STATE UNIVERSITY GREENSBORO, N.C.

TRANSPORTATION CHARGES: FOB-DESTINATION, FREIGHT CHARGES MUST BE INCLUDED IN ITEMS LISTED, NOT LISTED AS A SEPARATE ITEM.

DESCRIPTIVE LITERATURE: All bids must be accompanied by complete descriptive literature, specifications and other pertinent data necessary for their evaluation as required by Par. 12 of the attached General Contract Terms & Conditions; otherwise, they will be subject to rejection.

EQUIPMENT ACCEPTANCE: Acceptance of the equipment and installation for the purpose of ownership, warranty start and payment, shall be granted by the State when the bidder has demonstrated to the State fulfillment of the IFB, provided in-service training, the system passing state testing with all mechanical, electrical and electronic circuitry components meeting the published specifications of the Manufacturer and of this IFB.

SPECIFICATIONS: The attached specifications are drawn around particular equipment for the purpose of establishing the quality level desired. Bidders are requested to offer their units closest to the specifications that will perform the functions required.

SUITABILITY FOR INTENDED USE: Bidders are requested to offer only comparable equipment which will provide the equivalent capabilities, features and diversity called for herein. The State reserves the right to evaluate all proposals for suitability for the required use and to award the one best meeting requirements and thought to be in the State's best interest.

AWARD OF CONTRACT: In addition to bid price, delivery, and specification compliance, consideration may be given to other factors such as, but not limited to, proven performance of equipment offered, adequate availability of service and parts, bidder's previous performance in contracts with the State and other users, and information obtained from references.

MAINTENANCE:

Cost of 1st year maintenance: (after 12 month warranty period) \$ _____

Cost of 2nd year maintenance: \$ _____

Cost of 3rd year maintenance: \$ _____

The maintenance cost noted above is to include all parts, labor, transportation, technician's travel and routine maintenance at no additional cost to the State.

MANUALS: Service manuals and operating instructions shall be provided for each piece of equipment. Delivery will not be considered complete until one copy of all manuals are delivered.

DELIVERY: Delivery will be made from _____ (City & State) within _____ consecutive calendar days after receipt of order.

WARRANTY: Bidder guarantees equipment offered and supplied by him as a result of this Invitation to be free from any and all defects in material and workmanship and warrants same for a period of at least one year.

BIDS ARE SUBJECT TO REJECTION UNLESS SUBMITTED ON THIS FORM

REFERENCES: Bidder must provide the names of users of the product being bid. Include units that are located in the area of North Carolina, South Carolina and Virginia.

NAME TELEPHONE	CONTACT	ADDRESS
-------------------	---------	---------

1. _____

2. _____

FURNISH, DELIVER, INSTALL AND TRAIN PERSONNEL IN USE OF:

MOLECULAR BEAM EPITAXIAL SYSTEM WITH THE FOLLOWING COMPONENTS IN ACCORDANCE WITH THE ATTACHED SPECIFICATIONS.

1. 1 EA INTRODUCTION CHAMBER

MFG. _____ MODEL# _____ \$ _____

2. 1 EA ROUGHING SYSTEM

MFG. _____ MODEL# _____ \$ _____

3. 1 EA EFFUSION CELLS BAKING FIXTURE

MFG. _____ MODEL# _____ \$ _____

4. 1 EA BUFFER CHAMBER

MFG. _____ MODEL # _____ \$ _____

5. 1EA GROWTH CHAMBER

MFG. _____ MODEL # _____ \$ _____

6.. 1 LOT SOURCE CELLS

MFG. _____ MODEL# _____ \$ _____

7. 1 LOT SUBSTRATE HOLDERS

MFG. _____ MODEL# _____ \$ _____

8.. 1 EA BAKEOUT SYSTEM

MFG. _____ MODEL# _____ \$ _____

BIDS ARE SUBJECT TO REJECTION UNLESS SUBMITTED ON THIS FORM

8. 1 EA BASIC ELECTRONICS CABINET/RACK

MFG. _____ MODEL# _____ \$ _____

9. 1 LOT CABLES AND ELECTRONICS EQUIPMENT

MFG. _____ MODEL# _____ \$ _____

10. 1 EA AUTOMATED CONTROL SYSTEM

MFG. _____ MODEL # _____ \$ _____

11. 1 EA SAFETY INTERLOCK SYSTEM

MFG. _____ MODEL # _____ \$ _____

TOTAL DELIVERED PRICE \$ _____

OPTIONAL COMPONENTS

1. 1 EA GATE VALVE AND NECESSARY PARTS FOR LOAD-LOCKING THE RHEED SCREEN.

MFG. _____ MODEL # _____ \$ _____

2. 1 EA GATE VALVE AND NECESSARY PARTS FOR LOAD-LOCKING THE FLUX MONITOR.

MFG. _____ MODEL # _____ \$ _____

3. 1 EA 1000C SUBSTRATE OUTGASSING STAGE IN THE BUFFER CHAMBER.

MFG. _____ MODEL # _____ \$ _____

4. 1 EA Ti BOOSTER FOR THE ION PUMP IN THE BUFFER CHAMBER

MFG. _____ MODEL # _____ \$ _____

5. LOT TRAINING PROGRAM FOR ONE PERSON ON THE SYSTEM PRIOR TO THE
DELIVERY

MFG. _____ MODEL # _____ \$ _____

MBE SYSTEM SUMMARY SPECIFICATION

A modular three inch substrate MBE system with

A. INTRODUCTION CHAMBER

1. Hinged rail for substrate trolley
2. Viton sealed rapid access door for sample in and out
3. 200° C internal bakeout
4. One substrate trolley/cassette to hold at least five substrates.
5. Ports for ion gauge and convectron gauge
6. One ion gauge and one convectron gauge with controller
7. Transfer rails
8. Roughing port with viton sealed valve and CF flange connected to roughing line
9. UHV pump port with pneumatic gate valve
10. One manual viton sealed metal bonnet VAT gate valve to isolate from Buffer Chamber
11. Chamber support frame
12. Vent valve
13. Water cooled chamber if available
14. Load lock chamber port should be compatible with future retrofit for cryopump pumping system.
15. Viewport
16. Balzer wide range 170 liters per second magnet bearing oil free turbo pump and controller connected to the UHV pump port (using the Roughing System as its backing pump.)

B. ROUGHING SYSTEM

Molecular-drag pump plus diaphragm pump with control unit with a low vacuum gauge (convectron or thermocouple gauge) and vent valve in the roughing line, vent valve. (Make a vacuum connection to assure this Roughing System also provides backing vacuum for the turbo pump in the introduction chamber).

B-1. EFFUSION CELLS BAKING FIXTURE

- Small volume chamber with water cooling
- Two ports for effusion cells
- Adapter pumping tube between the load lock turbo and gatevalve (T -piece) with a metal valve to the baking fixture. The metal valve shall isolate the baking fixture from the vacuum system and also provide roughing port for the baking fixture.
- should be bakeable to 1600C
- one nude ion gauge in the pumping tube

C. BUFFER CHAMBER

1. Second trolley/cassette for storage
2. Transfer rails

3. One manual viton sealed metal bonnet VAT gate valve to isolate from Growth Chamber
4. One port for nude ion gauge
5. Ion gauge and controller
6. Appropriate transfer viewports
7. Appropriate transfer mechanism to transfer sample into Growth Chamber
8. One port for substrate outgassing stage, preferably water cooled
9. One port for 220 1/s triode ion pump or CT-8 cryopump
10. 220 1/s triode ion pump, power supply and controller
11. Blank port for system expansion
12. Chamber support frame
13. Vent or roughing line port

D. GROWTH CHAMBER

1. LN₂ shroud for substrate with LN₂ feedthrough
2. LN₂ panel with feedthrough and Mo isolation fence for thermal and optical isolation between cells.
3. One port for RHEED GUN
4. A bellows assembly for RHEED gun angle mechanical adjustment
5. A port for RHEED screen with high quality phosphorous screen and a manual screen shutter
6. One port for RGA
7. One roughing port with metal-sealed valve and CF flange for connection to roughing line
8. One transfer viewport with manual shutter
9. At least two source cell viewports with manual shutters to view all of the effusion cells.
10. One port for nude ion gauge for monitoring the background pressure
11. Nude ion gauge and controller
12. Three ports for pumps of 400 1/s triode ion pump, separate Ti-sublimation pump, and 2200 1/s turbo pump or 1500 1/s in future cryopump (blank flanges as spare parts for these pump ports)
13. One 400 1/s ion pump with power supply and controller
14. One pneumatic viton sealed metal bonnet VAT gate valve isolating the ion pump from the growth chamber
15. Ti-ball sublimation pump with power supply and controller and LN₂ cooling shroud, separating from ion pump.
16. One port for substrate manipulator (one blank flange as spare part for this port)
17. The heater/manipulator assembly for three inch substrate with substrate rotation controller, substrate heater DC power supply and Eurotherm Model 905 temperature controller, and substrate heating stage water cooled. The thermocouple junction in the substrate heating stage should not expose to any source fluxes.
18. Optical access to the substrate backside in the substrate manipulator (for backside pyrometer or CI optical temperature measurement and control)
19. Provision for biasing the substrate and the high voltage feedthrough
20. One port for flux monitor assembly (one blank flange as spare part for this port)
21. Flux monitor assembly with monitor position controller and ion gauge controller, and motor-driven/interlocked

22. One pair of ellipsometry blank ports with ports for shutters
23. Two pair of additional optical blank ports (angles to be specified when placing the order)
24. One 4.5" CF pyrometer port in the source flange center perpendicular to the substrate in the growth position with full screen shutter. The shutter shelled be able to be electropneumatically/step0motor actuated. (one 4.5" CF bland flange as spare part)
25. 600° C bakeable optical window for the pyrometer view port
26. Nine ports on the source flange for the effusion cells (a blank flange for each port as spare parts)
27. Ports for every source flux shutters
28. One port for the main shutter
29. Electropneumatically/step-motor actuated shutters for every sources and main shutter with control unit. (All the shutter actuation time should be adjustable in the range of 50-200 ms and one million cycles life time guaranteed. Shutter operation should be smooth and vibration free)
30. A hand-held remote effusion cell shutter controller
31. Chamber support frame
32. N₂ gas or air distributor for pneumatically actuated shutters and gate valves if the shutters are pneumatically driven in the system.
33. Interlocked water purge safety equipment for removing water from all the source cells and substrate stage water cooling jackets in case of an electric power cut-off.
34. Chamber and the system bench should be compatible with future retrofit of gas source MBE pumping system

E. SOURCE CELLS

1. Three dual filament low flux transient effusion cells, large capacity (85 cc) crucible cells for Ga and In sources
2. One cold lip Effusion Cell for Al source (minimum 30cc)
3. Two Knudsen dopant cells (5 cc minimum capacity and dopants to be specified at the time of order placement)
4. One As valved cracker with automated valved positioner
5. One Sb valved cracker with automated valved positioner

Each of the above cells should include appropriate crucible (the exact crucible will be specified at the time of purchase), power supply/Eurotherm Model 905 temperature controller, cable and water cooling enclosure. (One spare blank flange to each of the source ports).

F. SUBSTRATE HOLDERS

Four 3" In-bonded

One 1cm x 1cm opening In-free

one 2" In-free

G. BAKEOUT

The system, including wires and cables, should be fully bakeable to 200°C. A thermostatically controlled bakeout system with temperature control unit with the ability to automatically shut down if any chamber pressure rises above predetermined limit during bakeout. Provision for automatic restart once the pressure has fallen to the required level. Each separate section of the MBE system has temerature control such that no part of the system exceeds 200°C. The bakeout

shrouds to be designed for easy modification to prevent bakeout of any cryopumps added onto the growth and introduction chambers.

H. MISCELLANEOUS EQUIPMENT

1. Basic electronics cabinet/rack
2. Cables and electronics equipment
3. It is preferable if all the electrical connections between the cabinets and the machine be provided in an overhead tray integral to the system

I. AUTOMATED CONTROL SYSTEM

The Automated Control System must provide the capability to control the critical functions of the MBE system during the growth of the materials and structures. It must be built on standard industry hardware platforms and operating systems, using distributed processing and providing multi-tasking operations which enables recipe creation and editing to proceed simultaneously with growth or other programs.

The system must provide a turnkey, automated process control system, with a single location for control, monitoring, recipe creation and data analysis. The operator must be able to modify the functionality, graphical interface, hardware configuration and control logic of any of the functions delivered with the system.

The system must provide precise control of multiple growth events, real-time status monitoring and manual override features, giving the user the capability to create, control and monitor growth conditions.

Control functions should include: (1) All cells and substrate temperature setpoint and ramping controls, both from recipe and from independent control commands, (2) control of degassing stage in the introduction and buffer chambers, (3) PID setting for source cells and substrate, (4) time sequencing of shutter operation (include main shutter and pyrometer viewpoint shutter) control both from recipe or from direct control commands, (5) valve position control for valved cracker both from recipe or from direct control commands, (6) ion gauge control and chamber vacuum monitoring and automatic reset system once the growth chamber vacuum $>10^{-5}$ torr, (7) control of substrate rotation and wafer stage position, (8) pneumatic gate valve control, (9) collection of RGA spectra from compatible equipment, (10) deposition recipe generation and (11) flexibility of control function extension and modification, (12) control of substrate and/or source cell temperature ramping during growth.

At least one upgrade of the software should be free. Auto pump down sequencer for load lock should also be included.

J. SAFETY INTERLOCK SYSTEM

Interlock system should be provided for the following safety consideration:

(1) Power loss: Backup power supply unit for keeping the group III cells temperature warm, water purge equipment for getting rid of the water from the water cooling enclosure of all the cells substrate.

(2) Vacuum loss: Once the vacuum in the growth chamber is below a certain value (say, 10^{-5} torr), system shall be automatically reset to idle condition and close the gate valve to the UHV pump.

K. COMPATIBILITY

The MBE system should be compatible with other standard auxiliary equipment. This includes equipment from other manufacturers, including ionization gauges, residual gas analyzers, furnaces, electron-beam evaporators, pumps, valves, optical pyrometers, and computer hardware and RHEED.

MBE source ports should be compatible with the gas source and the system should be easily expandable to gas source MBE system with minimum modification.

L. SYSTEM LAYOUT

A diagram of the complete system layout should be provided. All manuals and circuit diagrams used in the MBE system which are appropriate for system operation and maintenance should be provided. Exact utility requirements and the location and sizes of the physical connections shall also be given. Utility requirements to list expected consumption for growth, idle and bakeout operation. List of requirements netted to install and operate the offerer's MBE machine to be provided. This should include building access, floor loading, wafer handling equipment, etc.

M. SYSTEM INSTALLATION, DELIVERY AND PAYMENT

The freight, insurance, delivery and installation costs should be included within the contract. A factory test of the system by the buyer should be included.

Because of the customization of this equipment the State will allow a progress payment plan as follows:

25% on order placement

65% upon installation, vacuum, and mechanical tests, that included 1-7 & 17 of the acceptance tests.

10% on completion of the rest of the acceptance test

N. ACCEPTANCE TEST

1. Growth and buffer chamber vacuum pressure $< 5 \times 10^{-11}$ torr and 5×10^{-10} torr, respectively, introduction chamber vacuum pressure $< 5 \times 10^{-8}$ torr.
2. Vacuum test: within 45 minutes or less, the growth chamber pressure pump down to 10^{-6} torr from atmospheric pressure. Following the end of a two days bakeout of the system, the growth chamber pressure should be better than 2×10^{-10} torr within 24 hours and better than 5×10^{-11} torr when cryopanel cooled. With all the sources at growth temperature (with valved cracker for As), substrate at 200°C , growth chamber pressure should be better than 1×10^{-9} torr (with LN_2 panel cooled).
3. N_2 gas (or air) distributor and other parts of the pneumatically driven system shall be demonstrated to be in good working order.
4. Introduction and Buffer chamber substrates heating to 200°C (thermo-couple reading).

5. Growth chamber substrate heater: heating uniformity on a semi-insulating GaAs substrate at 600°C should be $\pm 2^\circ\text{C}$ (pyrometer measurement) on a 3" substrate.
6. Growth chamber substrate temperature stability (thermo-couple reading) $\pm 0.2^\circ\text{C}$ (thermo-couple reading) at typical growth temperature of 500-600°C within 3 hours without substrate rotation, $\pm 0.4^\circ\text{C}$ (thermo-couple reading) within 2 hours with substrate rotation at 50 RPM. The thermo-couple in the substrate heater should not expose to any source fluxes.
7. To test the growth chamber substrate heating and substrate mounting reproducibility, the In-bonded Mo blocks provided shall be mounted one at a time on the substrate heating stage in the growth position, for a total more than five times and each time Mo block shall be heated up to 550°C (thermo-couple reading). It will be stabilized under the same condition and the surface temperature of Mo shall be measured by the pyrometer under the same condition. The temperature (of the Mo block surfaces) as determined from the pyrometer measured in this way should be within $\pm 2^\circ\text{C}$.
8. Eurotherm controller temperature stability $\pm 0.1^\circ\text{C}$ at typical respective source temperatures (thermo-couple reading) and flux stability $< \pm 1\%$ (according to the flux monitor reading or RHEED oscillation measurement, whichever is more accurate) within 3 hours.
9. The As and Sb valved crackers temperature should be stable within $\pm 0.2^\circ\text{C}$ and flux stability $< 2\%$ as measured by the flux monitor during 3 hours.
10. The fluxes from the As and Sb valved crackers should have a linear response to the valve opening no matter in which way a set valve opening is reached. The fluxes should have sharp response and square shape trace to valve operations with flux reproducibility better than 4%.
11. Group III source flux reproducibility $< 2\%$ as measured by the flux monitor.
12. $\pm 1\%$ homogeneity in actual growth over the 3" Si substrate area with minimized level dependence: 1 μm GaAs layer will be grown and the thickness of the layer over the wafer will be measured using the Tencore surface profiler.
13. Shutter operation-related flux transient of group III sources at their growth temperature: for Ga, In and for Al should be less than 1% and 3%, respectively as measured by the flux monitor.
14. All the source flux shutters actuation time should be adjustable within 50 to 200 ms range. Shutter operation should be smooth, soft and vibration free.
15. To check the shutter performance and the cooling efficiency of the LN_2 cryoshroud and cryopanel, the following test shall be performed. When As source flux is in 10^{-5} torr regime and Ga, In, Al and Sb source are all at the respective growth temperatures with individual source shutters closed and the main shutter open, the flux monitor reading at the growth position should be better than 5×10^{-8} torr, and with the main shutter closed, the flux monitor reading should be better than 5×10^{-5} torr.
16. To check if the main shutter completely shields the entire substrate and from all the source fluxes, the following experiment shall be performed: a 2" (100) GaAs wafer shall be preheated to desorb oxide of the surface oxide. RHEED picture should be clear with clear reconstruction patterns.

Next with the substrate to room temperature, all the sources at the respective growth temperatures (namely heat up Ga, In and Al furnaces and set As and Sb crackers temperature and valve positions to a condition of common growth) with their individual shutters open but the main shutter in the closed position no degradation in the RHEED pattern should be observed.

17. Wobble of the substrate in the growth chamber when rotating should be less than 0.1° . Measurement: 2" Si or GaAs wafer shall be mounted on Mo substrate holder with In or In-free

substrate holder. A He-Neon laser beam shall be incident from one of the ellipsometry ports onto the substrate surface and the reflected light spot from another ellipsometry port shall be measured using a silicon photodetector mounted on a micropositioner or photosensitive film. A wobble during the substrate rotation will cause the change in the position of the reflected light spot and this shall be recorded to calculate the substrate wobble. Material Purity - Electrical and Optical Properties

18. Residual background of MBE grown layer of GaAs should be $n < 5 \times 10^{14} \text{ cm}^{-3}$ with 77K Hall mobility exceeding $70,000 \text{ cm}^2/\text{Vs}$ and oval defects density $< 200 \text{ cm}^{-3}$ within 10 runs of growth after system installation.

19. 4K PL on GaAs and $\text{Ga}_{0.7}\text{Al}_{0.3}\text{As}$ should be able to resolve excitonic features.

20. Alloy compositional uniformity: $\text{Ga}_{1-x}\text{Al}_x\text{As}$ of 5000Å thick should exhibit compositional uniformity, $\pm 1.5\%$ across a 2" sample (e.g. for $x=0.25$, measured x should fall within the limits 0.245-0.255). All mole fractions measurements shall be made using PL.

21. Interface Abruptness: A symmetrical single quantum well structure containing GaAs quantum well with $\text{Ga}_{0.7}\text{Al}_{0.3}\text{As}$ barriers shall be grown on (100) GaAs and PL at 4K will be tested. The structure shall be GaAs (100) \1μm GaAs buffer \0.4μm $\text{Ga}_{0.7}\text{Al}_{0.7}\text{As}$ barrier \100Å GaAs \2000 Å $\text{Ga}_{0.7}\text{Al}_{0.3}\text{As}$ barrier \50 Å GaAs protect layer and the FWHM for this well should be $< 5 \text{ meV}$.

22. Uniformity of quantum well structure: The above structure shall be mapped by 4K PL. variation in QW emission wavelength should be $< \pm 2\%$ over 2" sample.

23. The Hall measurement results obtained on AlSb/InAs/GaAs(100) [Ref: Uppal et al. (J. Cryst. Growth 111, 623 (1991))] should be reproduced. The structure conceits of InAs/AlSb heterostructure grown on the buffer layer of 0.5μm AlInSb/AlSb on GaAs (100) substÅ rate. All the grown layers are undoped. Results: 300 K sheet carrier density $7 \times 10^{11} \text{ cm}^{-2}$ with corresponding electron Hall mobility of $23,000 \text{ cm}^2/\text{Vs}$, and 77 K carrier density $4 \times 10^{11} \text{ cm}^{-2}$, with an electron Hall mobility of $76,000 \text{ cm}^2/\text{Vs}$.

24. The GaSb layers shall be directly grown on smi-insulating GaAs (100) substracts. The undoped layer should exhibit a background carrier concentration of better than $1 \times 10^{16}/\text{cm}^{-3}$ with a room temperature electron mobility of $6000 \text{ cm}^2/\text{V-sec}$ [Ref: Chen and Cho, J. Appl. Phys. 70, 277 (1991)].

25. Doping Uniformity: The Bulk GaSb doped n and p-type should exhibit uniformity better than $< \pm 3.5\%$ for 3" wafers when doped to approximately $1 \times 10^{17}/\text{cm}^3$.

Uniformities shall be evaluated employing evaporated metal contact C-V measurements.

26. 2-DEG Mobility in thick spacer HEMT Structure

The buffer layer will consist of 25 period superlattice 185Å $\text{Al}_{0.23}\text{Ga}_{0.77}\text{As}$ -i/ 15Å GaAs-i and thick 2μm GaAs layer grown on SI GaAs substrate. This will be followed by spacer layer of 250Å $\text{Al}_{0.23}\text{Ga}_{0.77}\text{As}$ -i/400Å $\text{Al}_{0.23}\text{Ga}_{0.77}\text{As}$ ($n=3 \times 10^{18}/\text{cm}^3$) /400Å GaAs ($n=3.9 \times 10^{18}/\text{cm}^3$) cap layer. Hall bridges will be defined by photolithography and alloyed In contacts will be applied. Such a structure should exhibit 77K mobility of $185,000 \text{ cm}^2/\text{Vsec}$ respectively.

**STATE OF NORTH CAROLINA
DEPARTMENT OF ADMINISTRATION
DIVISION OF PURCHASE AND CONTRACT**

GENERAL CONTRACT TERMS AND CONDITIONS

FORM R-1

1. **ACCEPTANCE AND REJECTION:** The State reserves the right to reject any and all bids, to waive any informality in bids and, unless otherwise specified by the bidder, to accept any item in the bid. If either a unit price or extended price is obviously in error and the other is obviously correct, the incorrect price will be disregarded.
2. **TIME FOR CONSIDERATION:** Preference may be given to proposals allowing not less than 30 days for consideration and acceptance.
3. **TAXES:** No taxes shall be included in any bid prices.
 - a. **FEDERAL:** Generally, states and political subdivisions are exempt from such taxes, as excise and transportation. Exemption is claimed under Registry No. 56-70-0047K as provided by Chapter 32 of the Internal Revenue Code.
 - b. **OTHER:** Bid prices are not to include any sales, import, or personal property taxes. To the extent applicable, they are to be invoiced as a separate item(s).
4. **RESALE PRICE MAINTENANCE:** The State of North Carolina has no Fair Trade law, and this or any other type of resale price maintenance exercised in prices offered will be subject to appropriate legal remedies.
5. **AFFIRMATIVE ACTION:** The successful bidder will take affirmative action in complying with all Federal and State requirements concerning fair employment and employment of the handicapped, and concerning the treatment of all employees, without regard to discrimination by reason of race, color, religion, sex, national origin or physical handicap.
6. **CONDITION AND PACKAGING:** Unless otherwise indicated in the bid, it is understood and agreed that any item offered or shipped on this bid shall be new and in first class condition, that all containers shall be new and suitable for storage or shipment, and that prices include standard commercial packaging.
7. **PERFORMANCE AND DEFAULT:** The State reserves the right to require performance bond from successful bidder, as provided by law, without expense to the State. Otherwise, in case of default of the contractor the State may procure the articles or services from other sources and hold the contractor responsible for any excess cost occasioned thereby.
8. **SAMPLES:** Samples of items, when required, must be furnished as stipulated herein, free of expense, and if not destroyed will, upon request, be returned at the bidder's expense. Request for the return of samples must be made within 10 days following opening of bids. Each individual sample must be labeled with bidder's name and item number.
9. **MANUFACTURERS' NAMES:** Any manufacturers' names, trade names, brand names, information and/or catalog numbers used herein are for purpose(s) of description and establishing general quality levels. Such references are not intended to be restrictive and products of any manufacturer may be offered.
10. **SPECIFICATION:** Any deviation from specifications indicated herein must be clearly pointed out; otherwise, it will be considered that items offered are in strict compliance with these specifications, and successful bidder will be held responsible therefor. Deviations must be explained in detail on an attached sheet(s).

11. **SAFETY STANDARDS:** All manufactured items and/or fabricated assemblies subject to operation under pressure, operation by connection to an electric source, or operation involving a connection to a manufactured, natural, or LP gas source shall be constructed and approved in a manner acceptable to the appropriate state inspector which customarily requires the label or re-examination listing or identification marking of the appropriate safety standard organization; such as the American Society of Mechanical Engineers for pressure vessels; the Underwriters' Laboratories and/or National Electrical Manufacturers' Association for electrically operated assemblies; or the American Gas Association for gas operated assemblies, where such approvals of listings have been established for the type(s) of devices offered and furnished. Further, all items furnished by the successful bidder shall meet all requirements of the Occupational Safety and Health Act (OSHA), and state and federal requirements relating to clean air and water pollution.
12. **INFORMATION AND DESCRIPTIVE LITERATURE:** Bidders are to furnish all information requested and in the spaces provided on the bid form. Further, as may be specified elsewhere, each bidder must submit with his proposal cuts, sketches, descriptive literature and/or complete specifications covering the products offered. Reference to literature submitted with a previous bid does not satisfy this provision. Bids which do not comply with these requirements will be subject to rejection.
13. **TRADE DISCOUNTS:** Trade discounts, when quoted should be reduced to a single percentage, for example, instead of 50, 10 and 5 percent, the discounts should be stated at 57¼%.
14. **AWARD AND PAYMENT:** As directed by statute, qualified proposals will be evaluated and acceptance made of the lowest and best proposal(s) determined most advantageous. Acceptance is to be confirmed by purchase order(s) issued on the part of the using agency, including shipping and billing instructions; the agency is responsible for all payments under the award, to be based on the contract price(s) in effect on the date order is placed.
15. **GOVERNMENTAL RESTRICTIONS:** In the event any Governmental restrictions may be imposed which would necessitate alteration of the material, quality, workmanship or performance of the items offered on this proposal prior to their delivery, it shall be the responsibility of the successful bidder to notify this Division at once, indicating in his letter the specific regulation which required such alterations. The State reserves the right to accept any such alterations, including any price adjustments occasioned thereby, or to cancel the contract.
16. **AGENTS:** Bids signed by Agent are to be accompanied by evidence of his authority.
17. **INSURANCE:** Before delivery of equipment, the contractor shall obtain from an insurance company duly authorized to do business in North Carolina, insurance as follows:
 - a. **Workmen's Compensation** - The contractor shall take out and maintain during the life of this contract Workmen's Compensation Insurance for all of his employees employed at the site of the project and in case any work is sub-let, the contractor shall require the sub-contractor similarly to provide Workmen's Compensation Insurance for all the latter's employees employed at the site of the project, unless such employees are covered by the protection afforded by the contractor.
 - b. **Public Liability and Property Damage** - The contractor shall take out and maintain during the life of this contract such Public Liability and Property Damage Insurance as shall protect him and any subcontractor performing work covered by this contract, from claims for damage or personal injury, including accidental death, as well as from claims for property damages which may arise from operations under this contract, whether such operations be by himself or by any subcontract, or by anyone directly or indirectly employed by either of them and the amounts of such insurance shall be as follows:

Public Liability Insurance in an amount not less than \$15,000 for injuries, including accidental death to any one person, and subject to the same limit for each person, in an amount not less than \$30,000 on account of one accident, and Property Damage Insurance in an amount not less than \$5,000.
 - c. **Proof of Carriage** - The contractor shall furnish the owner one copy of certificate from insurance company as proof of carriage of insurance required as specified above.

- d. It is agreed that the coverage as stated shall not be canceled or changed until ten days after written notice of such termination or alteration has been sent by registered mail to the office of the agency for whom the work is performed.
18. **PATENTS:** The contractor shall hold and save the State, its officers, agents and employees, harmless from liability of any kind, including costs and expenses on account of any patented or unpatented invention, articles, device or appliance manufactured or used in the performance of this contract, including use by the government.
19. **ADVERTISING:** In submitting his proposal, bidder agrees not to use the results therefrom as a part of any commercial advertising without prior approval of the Division of Purchase and Contract.
20. **LIST OF BIDDERS:** Prospective bidders may be included on or removed from bid lists after taking into consideration responsiveness as a bidder and other factors as listed in the North Carolina Administrative Code, Section 5B.0302.
21. **PATENT AND COPYRIGHT INDEMNITY:** VENDOR will defend or settle, at its own expense, any action brought against Customer to the extent that it is based on a claim that the product (s) provided pursuant to this agreement infringe any U. S. copyright or patent; and will pay those costs, damages and attorney's fees finally awarded against Customers in any such action attributable to any such claim, but such defense, settlements and payments are conditioned on the following (1) that VENDOR shall be notified promptly in writing by Customer of any such claim; (2) that VENDOR shall have sole control of the defense of any action on such claim and of all negotiations for its settlement or compromise; (3) that Customer shall cooperate with VENDOR in a reasonable way to facilitate the settlement of defense of such claim; (4) that such claim does not arise from Customer modifications not authorized by the VENDOR or from the use or combination of products provided by the VENDOR with products provided by the Customer or by others; and (5) should such product(s) become, or in the VENDOR'S opinion likely to become, the subject of such claim of infringement, then Customer shall permit VENDOR, at VENDOR'S option and expense, either (a) to procure for Customer the right to continue using the product (s), or (b) replace or modify the same so that it becomes noninfringing and performs in a substantially similar manner to the original product; or (c) upon failure of (a) or (b) despite the reasonable efforts of the VENDOR for a sold product or licensed software, return the price paid for the licensed software and any product dependent thereon.
22. **AVAILABILITY OF FUNDS:** Any and all payments of compensation of this specific transaction, its continuing or any renewal or extension are dependent upon and subject to the allocation of appropriation of funds to the Agency for the purpose set forth in this agreement. (NCGS 143-34.2)
23. **SITUS:** The place of all contracts, transactions, agreements, their situs and forum, shall be North Carolina, where all matters, whether sounding in contract or tort, relating to the validity, construction, interpretation and enforcement shall be determined.
24. **GOVERNING LAWS:** All contracts, transactions, agreements, etc. are made under and shall be governed by and construed in accordance with the laws of the State of North Carolina.
25. **ADMINISTRATIVE CODE:** Bids, proposals, and awards are subject to applicable provisions of the North Carolina Administrative Code.

INSTRUCTIONS TO BIDDERS

1. Read and comply as necessary with attached General Contract Terms and Conditions.
2. TAXES: See attached General Conditions, Paragraph 3.
3. Unless otherwise requested, only one copy of Bid Form need be submitted, and this copy must be typewritten or printed in ink.
4. CASH DISCOUNTS: Bidders are urged to compute all discounts for prompt payment into the bud price(s), with terms of payment to be net, 30 days. Such bids may receive preference. If a cash discount is offered and accepted, it will be considered earned if paid within thirty days after the receipt of correct invoice or acceptance of goods, whichever is later.
5. Sign bid in ink in space provided below.
6. It is bidder's responsibility to have his bid in this office by the specified time and date of opening.
7. Address and mark your bid as shown below and MAKE CERTAIN TO INDICATE IDENTIFYING BID NUMBER

NOTE

BIDDER IS CAUTIONED THAT ANY MAIL
REQUIRING SPECIAL HANDLING
('CERTIFIED,' 'REGISTERED,' ETC.) IS
OFTEN DELAYED AND MAY RESULT IN
YOUR BID BEING LATE.

BID NO. 404378

NC DEPARTMENT OF ADMINISTRATION
DIVISION OF PURCHASE & CONTRACT
116 WEST JONES STREET
RALEIGH, NC 27603-8002

EXECUTION OF BID

IMPORTANT: BE SURE YOUR ENVELOPE IS ADDRESSED AND MARKED AS INDICATED ABOVE.

DATE _____

In compliance with this Invitation for Bids, and subject to all the conditions herein, the undersigned offers and agrees, if this bid be accepted within _____ days from the date of the opening, to furnish any or all items upon which prices are quoted, at the price set opposite each item, and unless otherwise specified, within _____ days after receipt of order. Cash Discount (See Instruction 4): _____ %

Pursuant to the provision of G.S. 143-54, under penalty of perjury the undersigned bidder certifies that this bid has not been arrived at collusively nor otherwise in violation of Federal or North Carolina antitrust laws.

BIDDER: _____ STREET: _____

SIGNED (IN INK): _____ P.O. BOX: _____

(Members of Firms or Person Authorized to Sign Bids for Corporation)

ABOVE SIGNATURE (TYPED): _____ CITY/STATE/ZIP: _____

TITLE: _____ TELEPHONE NUMBER: _____

BIDDER'S E.I. (FEDERAL SOCIAL SECURITY IDENTIFICATION) NUMBER _____

NORTH CAROLINA SALES & USE TAX REGISTRATION NUMBER _____

ACCEPTANCE OF BID

Acceptance in accordance with this copy _____

DIVISION OF PURCHASE AND CONTRACT

Date: _____ BY _____

PURCHASING AGENT

BIDS ARE SUBJECT TO REJECTION UNLESS SUBMITTED ON THIS FORM

APPENDIX B

Invitations for bids on the high resolution x-ray diffractometer system

STATE OF
NORTH CAROLINA

INVITATION FOR BIDS NO.

501623

Refer ALL Inquiries:

Bids will be
publicly opened: **Thursday, April 6, 1995**

To: **Bobbie Summers**

Commodity: **X-RAY DIFFRACTOMETER
SYSTEM**

N.C. Department of Administration
Division of Purchase and Contract
116 West Jones Street
Raleigh, N.C. 27603-8002

Contract Type: **Open Market Contract**

Tel. No. (919)733-6604

Agency Req. No. 03179

Issue Date: **March 22, 1995**

Mailing List No. 900-20-00

NOTICE TO BIDDERS

Sealed bids, subject to the conditions made a part hereof, will be received at this office until 2 o'clock p.m. on the day of bid opening and then publicly opened, for furnishing and delivering the commodity as described herein. Refer to Instructions to Bidders, Item 9 for proper mailing instructions.

Bids and/or addenda submitted via facsimile (FAX) machine in response to this Invitation for Bids will not be acceptable. Bids are subject to rejection unless submitted on this form.

EXECUTION

compliance with this Invitation for Bids, and subject to all the conditions herein, the undersigned offers and agrees to furnish and deliver any or all items upon which prices are bid, at the prices set opposite each item within the time specified herein. I certify that this bid is made without prior understanding, agreement, or connection with any firm, corporation, or person submitting a bid for the same commodity, and is in all respects fair and without collusion or fraud. Pursuant to the provision of G.S. 143-54, under penalty of perjury the undersigned bidder certifies that this bid has not been arrived at collusively or otherwise in violation of Federal or North Carolina law.

Failure to execute bid prior to submittal shall render bid invalid.

BIDDER:		FEDERAL ID OR SOCIAL SECURITY NO.	
STREET ADDRESS:	ZIP:	P. O. BOX:	ZIP:
CITY & STATE:		TELEPHONE NUMBER:	
TYPE OR PRINT NAME & TITLE OF PERSON SIGNING:		TOLL FREE TEL. NO. (800) -	
AUTHORIZED SIGNATURE:	DATE:	FAX NUMBER:	

Offer valid for 45 days from date of bid opening unless otherwise stated here: _____ days (See Instructions to Bidders, Item 7)
Prompt Payment Discount: _____ % _____ days (See Instructions to Bidders, Item 8)

"NO BID" ☐ Reason: _____
☐ Remove my Company from the mailing list for this commodity only.
(See Instructions to Bidders, Item 5)

ACCEPTANCE OF BID

If any or all parts of this bid are accepted by the State of North Carolina, an authorized representative of the Division of Purchase and Contract shall affix their signature hereto and this document and the provisions of the Instructions to Bidders, special terms and conditions specific to this invitation for Bids, the specifications, and the North Carolina General Contract Terms and Conditions shall then constitute the written agreement between the parties. A copy of this acceptance will be forwarded to the successful bidder(s).

FOR STATE USE ONLY

Offer accepted and contract awarded this _____ day of _____, 19____ as indicated on attached
Certification by: _____ (Authorized representative of the Division of Purchase and Contract)

INSTRUCTIONS TO BIDDERS

1. **READ, REVIEW AND COMPLY:** It shall be the bidder's responsibility to read this entire document, review all enclosures and attachments, and comply with all requirements specified herein.

2. **NOTICE TO BIDDERS:**

All bids are subject to the provisions of the Instructions to Bidders, special terms and conditions specific to this Invitation for Bids, the specifications, and the North Carolina General Contract Terms and Conditions.

The State objects to and will not evaluate or consider any additional terms and conditions submitted with a bidder response. This applies to any language appearing in or attached to the document as part of the bidder's response. **DO NOT ATTACH ANY ADDITIONAL TERMS AND CONDITIONS.**

By execution and delivery of this document, the bidder agrees that any additional terms and conditions, whether submitted purposely or inadvertently, shall have no force or effect.

3. **DEFINITIONS:**

BIDDER: Company, firm, corporation, partnership, individual, etc., submitting a response to an Invitation for Bids.

TERM CONTRACT: A contract generally intended to cover all normal requirements for a commodity for a specified period of time based on estimated quantities only.

STATEWIDE TERM CONTRACT: A Term Contract for all agencies, unless exempted by statute, rule, or special term and condition specific to this bid.

AGENCY SPECIFIC TERM CONTRACT: A Term Contract for a specific agency.

OPEN MARKET CONTRACT: A contract for the purchase of a commodity not covered by a term contract.

4. **EXECUTION:** Failure to sign under EXECUTION section will render bid invalid.

NO BID: If submitting a "NO BID", respond by returning only the first page, checking the appropriate block or blocks under the NO BID section.

6. **ORDER OF PRECEDENCE:** In cases of conflict between specific provisions in this bid, the order of precedence shall be (1) special terms and conditions specific to this bid, (2) specifications, (3) North Carolina General Contract Terms and Conditions, and (4) Instructions to Bidders.

7. **TIME FOR CONSIDERATION:** Unless otherwise indicated on the first page of this document, bidder's offer shall be valid for 45 days from the date of bid opening. Preference may be given to bids allowing not less than 45 days for consideration and acceptance.

8. **PROMPT PAYMENT DISCOUNTS:** Bidders are urged to compute all discounts into the price offered. If a prompt payment discount is offered, it will not be considered in the award of the contract except as a factor to aid in resolving cases of identical prices.

9. **MAILING INSTRUCTIONS:** Mail only one fully executed bid document, unless otherwise instructed, and only one bid per envelope. Address envelope as shown below:

BID NO. 501623
NC DEPARTMENT OF ADMINISTRATION
DIVISION OF PURCHASE AND CONTRACT
116 WEST JONES STREET
RALEIGH, NC 27603-8002

It is the responsibility of the bidder to have the bid in this office by the specified time and date of opening.

10. **SPECIFICATIONS:** Any deviation from specifications indicated herein must be clearly pointed out; otherwise, it will be considered that items offered are in strict compliance with these specifications, and bidder will be held responsible therefore. Deviations shall be explained in detail. **The bidder shall not construe this paragraph as inviting deviation or implying that any deviation will be acceptable.**

11. **INFORMATION AND DESCRIPTIVE LITERATURE:** Bidder is to furnish all information requested and in the spaces provided in this document. Further, if required elsewhere in this bid, each bidder must submit with their bid sketches, descriptive literature and/or complete specifications covering the products offered. Reference to literature submitted with a previous bid will not satisfy this provision. Bids which do not comply with these requirements will be subject to rejection.



12. **RECYCLING AND SOURCE REDUCTION:** It is the policy of this State to encourage and promote the purchase of products with recycled content to the extent economically practicable, and to purchase items which are reusable, refillable, repairable, more durable, and less toxic to the extent that the purchase or use is practicable and cost-effective.

We also encourage and promote using minimal packaging and the use of recycled/recyclable products in the packaging of commodities purchased. However, no sacrifice in quality of packaging will be acceptable. The company remains responsible for providing packaging that will protect the commodity and contain it for its intended use.

Companies are strongly urged to bring to the attention of the purchasers in the Division of Purchase and Contract those products or packaging they offer which have recycled content and that are recyclable.

13. **CLARIFICATIONS/INTERPRETATIONS:** Any and all questions regarding this document must be addressed to the purchaser named on the cover sheet of this document. Do not contact the user directly. Any and all revisions to this document shall be made only by written addendum from the Division of Purchase and Contract. The bidder is cautioned that the requirements of this bid can be altered only by written addendum and that verbal communications from whatever source are of no effect.

14. **ACCEPTANCE AND REJECTION:** The State reserves the right to reject any and all bids, to waive any informality in bids and, unless otherwise specified by the bidder, to accept any item in the bid. If either a unit price or extended price is obviously in error and the other is obviously correct, the incorrect price will be disregarded.

15. **REFERENCES:** The State reserves the right to require a list of users of the exact item offered. The State may contact these users to determine acceptability of the bid. Such information may be considered in the evaluation of the bid.

16. **TAXES:**

FEDERAL: All agencies participating in this contract are exempt from Federal Taxes, such as excise and transportation. Exemption forms submitted by the contractor will be executed and returned by the using agency.

OTHER: Prices offered are not to include any personal property taxes, nor any sales or use tax (or fees) unless required by the North Carolina Department of Revenue.

17. **AWARD OF CONTRACT:** As directed by statute, qualified bids will be evaluated and acceptance made of the lowest and best bid most advantageous to the State as determined upon consideration of such factors as: prices offered; the quality of the articles offered; the general reputation and performance capabilities of the bidders; the substantial conformity with the specifications and other conditions set forth in the bid; the suitability of the articles for the intended use; the related services needed; the date or dates of delivery and performance; and such other factors deemed by the State to be pertinent or peculiar to the purchase in question. Unless otherwise specified by the State or the bidder, the State reserves the right to accept any item or group of items on a multi-item bid.

In addition, on TERM CONTRACTS, the State reserves the right to make partial, progressive or multiple awards; where it is advantageous to award separately by items; or where more than one supplier is needed to provide the contemplated requirements as to quantity, quality, delivery, service, geographical areas; other factors deemed by the State to be pertinent or peculiar to the purchase in question.

18. **MAILING LISTS:** Prospective bidders may be included on or removed from mailing lists after taking into consideration responsiveness as a bidder and other factors as listed in the North Carolina Administrative Code, Title 1, Department of Administration, Chapter 5, Purchase and Contract, Section 5B.0302.

19. **TABULATIONS:** Verbal tabulations of bids and award information can be obtained by calling the tabulation number, (919) 733-4528. Tabulations will be available upon request no earlier than 9:00 a.m. on the first working day following the date of opening. Requests for lengthy or written tabulations cannot be honored.

20. **HISTORICALLY UNDERUTILIZED BUSINESSES:** Pursuant to General Statute 143-48 and Executive Order #77, the State invites and encourages participation in this procurement process by businesses owned by minorities, women, and the disabled, and by disabled business enterprises.

21. **CONFIDENTIAL INFORMATION:** As provided by statute and rule, the Division of Purchase and Contract will consider keeping trade secrets which the bidder does not wish disclosed confidential. Each page shall be identified in boldface at the top and bottom as "CONFIDENTIAL" by the bidder. Cost information shall not be deemed confidential. In spite of what is labeled as a trade secret, the determination whether it is or not will be determined by North Carolina law.

22. **SAMPLES:** Sample of items, when required, must be furnished as stipulated herein, free of expense, and if not destroyed will, upon request be returned at the bidder's expense. Request for the return of samples must be made within 10 days following date of bid opening. Otherwise the samples will become State property. Each individual sample must be labeled with the bidder's name, bid number, and item number. A sample on which an award is made, will be retained until the contract is completed, and then returned, if requested, as specified above.

MISCELLANEOUS: Masculine pronouns shall be read to include feminine pronouns, and the singular of any word or phrase shall be read to include the plural and vice versa.



USER: N.C. A & T State University, Electrical Engineering, Greensboro, N.C.

TRANSPORTATION CHARGES: FOB Destination. Freight charges must be included in the price of each item listed, not as a separate item.

DELIVERY: Early delivery is requested and bidder is urged to state earliest guaranteed delivery. The State reserves the right to evaluate delivery offered as a factor in determining the award of the proposed contract. Delivery will be made from _____ (City & State) within _____ consecutive days after receipt of order.

PAYMENT: Payment will be made **NET 30 DAYS** after receipt of correct invoice or the acceptance of the goods or (Services) whichever is later. There will be no prepayment. Duty, if applicable, must be included in the total price.

DESCRIPTIVE LITERATURE: All bids must be accompanied by complete descriptive literature, specifications and other pertinent data necessary for their evaluation as required by Par. 12 of the attached General Contract Terms & Conditions; otherwise, they will be subject to rejection.

WARRANTY: Bidder guarantees equipment offered by him to be free from any and all defects in material and workmanship and warrants same for a period of 12 months, such warranty to cover cost of all service, parts, labor and travel to and from point of service. Effective starting date of all warranties shall be upon acceptance by the State.

LIABILITY:

A. VENDOR'S liability to the STATE or for claims by the STATE based on injury to any third party for personal injury or damage to real property or tangible personal property shall be unlimited. This shall include any claim for which VENDOR is found to be legally liable arising from the failure of any VENDOR supplied product, replacement parts furnished by VENDOR, or of and VENDOR licensed program to operate in any material respect in accordance with any representation by VENDOR, whether in VENDOR'S, response to any Invitation of Bid or Proposal by the STATE, or in any published specifications or literature, or failure arising from services rendered by VENDOR'S employees. Claims shall not be limited by any clause whether found in any agreement between VENDOR and the STATE or in any VENDOR invoice or any other writing that purports to limit the remedies available to the STATE arising out of such failure.

B. VENDOR'S liability as described in paragraph A shall include the repair, restoration or replacement, within a reasonable time, of all damaged or destroyed, real or tangible personal property including buildings, furniture, fixtures, supplies, computer hardware, software and associated equipment (VENDOR and NON-VENDOR supplied), and information storage media of whatever description together with duplication of data files from existing STATE backup media. In addition, VENDOR'S liability for damages described in paragraph A shall include all damages suffered by the STATE, whether such damages are or might be classified as direct or consequential, which require the expenditure of public moneys (1) reasonably required to restore the Product (s) involved to its full original operational capability, (2) for temporary remedial measures reasonably required to perform any of the functions of the involved Product (s) during the restoration period, and (3) to pay any penalties imposed on the STATE by and Federal entity which penalties are the result of interruptions caused by the failure of any VENDOR product (s) or arising from services rendered by VENDOR'S employees for which VENDOR is found to be legally liable.

C. Except as specifically provided above, in no event will VENDOR be liable for any damages caused by the STATE'S failure to perform the STATE'S responsibilities, or for any lost profits, lost savings or other economic consequential damages even if VENDOR has been advised of the possibility of such damages, or for any claim by the STATE based on any third party claim except as provided in paragraphs A and B above.

D. Except as provided above, any clauses in any agreements between the VENDOR and STATE that purport to limit remedies available to the STATE remain in force, however VENDOR covenants that in any dispute with the STATE regarding damages covered by the preceding paragraphs A through C, such clauses do not, nor will they be pleaded to, bar such damages.

E. User Installed Software Only: Notwithstanding any other provision contained herein, for user installed software, the liability of the vendor shall be limited to the replacement of the defective software, or the full refund of the price paid, at the option of the STATE.

F. Except as provided above, nothing contained herein shall be construed to limit any remedy, at law or in equity, available to either party.



BIDDER: _____

SERVICE: Provide response time, telephone information, and location from which service will be provided.

Maximum on-site response time to this location
after receipt of service call:

Hours: _____

Provide toll-free (800) number:

800/ _____

Bidder will accept collect call for service?

Yes/No _____

Provide telephone number:

Address of local service facility: _____

List Service Representatives
and Business Telephone: _____

List Charges for Travel:

Labor: _____

Mileage: _____

Hotel & Meals: _____

REFERENCES: Bidder must provide the names of users of the product being bid. Include units that are located in the area of North Carolina, South Carolina and Virginia.

	NAME	CONTACT	ADDRESS	TELEPHONE
1.	_____	_____	_____	_____
2.	_____	_____	_____	_____
3.	_____	_____	_____	_____

MAINTENANCE OPTION: (After 12 Month Manufacturer Warranty)

	LABOR AND PARTS ONLY	LABOR ONLY
Cost of 2nd year maintenance:	\$ _____	\$ _____
Cost of 3rd year maintenance:	\$ _____	\$ _____
Cost of 4th year maintenance:	\$ _____	\$ _____
Cost of 5th year maintenance:	\$ _____	\$ _____

The above maintenance shall maintain the system specifications and performance level in accordance with the manufacturer's published specifications and of this IFB. It shall include all parts, all remedial maintenance labor, all travel and living expenses incurred. Coverage shall be for 8:00 AM to 5:00 PM, Monday through Friday, except State recognized holidays and shall include a minimum of two (2) preventive and safety maintenance inspections per year. The State has the option to accept the maintenance coverage at any time within the 12 month warranty period and to elect a billing cycle of preference. At the States discretion, this contract may be canceled and all unapplied payments shall be promptly and fully refunded.

NOTE: Bids may be detailed on additional paper and attached to the bid package, but the original bid forms of this IFB must be completed. Include manufacturer, model number, item list price, discount level, item net price, and total delivery price. The inclusion of terms and conditions of sale will constitute grounds for rejection of the Bid.



URNISH, DELIVER, OFF-LOAD, INSTALL AND PROVIDE ON-SITE TRAINING:

The equipment listed below serves as a reference for bidders of other manufacturers and models. Each item that is bid must be functionally equivalent to the referenced products and in accordance with the attached specifications.

PART A:

1. 1 Ea. (Model Bede Scientific 200 or functional equivalent) Double Crystal X-Ray Diffractometer with:
- Dual motorized 360° circles.
 - Motorized rotary table under first circle to set Bragg angle by computer software control.
 - Motor driven X-Ray Detector for the sample (2nd) circle.
 - Minicam II Computer Interface and X-Ray Detector System.
 - Bede EDR Low Noise, (less than .2CPS background), Scintillation Counter Tube and Power Supply. Linear to 700,000 CPS
 - X-Ray beam limiting aperture bar.
 - Fixed Collimator bracket.
 - Adjustable mounting plate for X-Ray beam alignment.
 - Full software, including rocking curve acquisition and analysis.
 - /x-Ray Reflection Topographic attachments

MFG: _____ MODEL# _____ \$ _____

2. 1 Ea. (Model Bede D³ or functional equivalent) Base and front end optics, including two (2) Silicon (220), two (2) or four (4) bounce channel cut crystals. Both crystals are computer software controlled for automatic selection.

MFG: _____ MODEL# _____ \$ _____

- 1 Ea. (Model Bede or functional equivalent) Sample Tilt Stage, including computer software control of 360° rotary, 40° tilt, 20 mm Zede and 0-2" x (horizontal) samples motions.

MFG: _____ MODEL# _____ \$ _____

4. 1 Ea. Three (3) K.W. X-Ray Generator constant potential. Custom radiation enclosure, Long Fine Focus Copper (Cu) Target X-Ray Diffraction Tube, (.4 x 12 mm), adapters to mount Bede 200 System and adjustable horizontal tube tower.

MFG: _____ MODEL# _____ \$ _____

5. 1 Ea. (Model RADS or functional equivalent) X-Ray Rocking Curve Simulation Software Program.

MFG: _____ MODEL# _____ \$ _____

6. 1 Ea. (Model Bede or functional equivalent) Wafermap Software. Provides data display of several rocking curves on one screen and display of FWHM, splitting, lattice mismatch and ternary composition.

MFG: _____ MODEL# _____ \$ _____

INSTALLATION OF THE ENTIRE SYSTEM BY A TRAINED ENGINEER, \$ _____
INCLUDING ALL EXPENSES

DISCOUNT (AS % OR \$) - (_____)

TOTAL PRICE \$ _____



BIDDER: _____

RT B: OPTIONAL ACCESSORIES:

1. 1 Ea. (Bede or functional equivalent) Triple Axis Attachment. Provides capability for 200/D³ System to be used as a Triple Axis Machine.

MFG: _____ MODEL# _____ \$ _____

2. 1 Ea. (Bede "REFS" or functional equivalent) X-Ray Grazing Incidence Reflectivity Simulation Software Program.

MFG: _____ MODEL# _____ \$ _____

REFERENCE: North Eastern Analytical Corporation, representing Bede Scientific.



SPECIFICATIONS FOR HIGH RESOLUTION X-RAY DIFFRACTION SYSTEM

ITEM	DESCRIPTION OF SPECIFICATIONS	YES	NO	IF "NO" PLEASE PROVIDE SPECIFICATIONS AND EXPLANATION OF ANY DEVIATION FROM THIS IFB'S SPECIFICATIONS
1	Must include motor driven rotary table under first circle to set Bragg angle by computer software control.			
2	All motions on both circles and all stages of the Double Crystal Diffractometer must be software computer controlled.			
3	Computer interface supplied with system must be capable of driving at least 12 motors.			
4	A software controlled motor driven detector about the second circle (sample), must be supplied with the system, for theta-two theta scans.			
5	First and second axis resolution of the diffractometer must be 0.5 arc seconds.			
6	Two channel-cut crystals, Silicon (220), 2 or 4 bounce software computer controlled must be provided for beam conditioning.			
7	System must allow a triple crystal attachment to be added at anytime.			
8	Simulation X-Ray rocking curve software (PC Based) must be supplied with the system.			
9	Glancing Incidence X-Ray Reflectivity, Double Crystal Rocking Curve and X-Ray Topography attachments and capability must be provided with the X-Ray system.			
10	Wafer mapping software must be provided with the system, providing automatic software computer controlled sample mapping.			
11	A sample translation stage with computer software control of (Z) Zede (20 mm), x (1" - 2"), Rotary (360°), and tilt (40°) motions must be supplied with the system.			
12	X-Ray Detector - An extended range X-Ray Scintillation Counter Tube must be supplied with the system and meet the following background and linearity specifications. Intrinsic background - Below 0.15 cps, linear dynamic range - 6.5 decades, linear response range - 400,000 cps, output - +5tt1, 500 ns pulse width.			
13	X-ray Generator - A 3 KW High Frequency ultra stable X-Ray generator with interlocked radiation safety enclosure, adjustable horizontal tube support and long fine focus (0.4 x 12 mm) copper (Cu) target X-Ray tube must be supplied with the system.			
14	Installation of the entire system by a trained Engineer plus expenses.			



NORTH CAROLINA
GENERAL CONTRACT TERMS AND CONDITIONS

1. **DEFAULT AND PERFORMANCE BOND:** In case of default by the contractor the State may procure the articles or services from other sources and hold the contractor responsible for any excess cost occasioned thereby. The State reserves the right to require performance bond or other acceptable alternative guarantees from successful bidder without expense to the State.
 2. **GOVERNMENTAL RESTRICTIONS:** In the event any Governmental restrictions are imposed which necessitate alteration of the material, quality, workmanship or performance of the items offered prior to their delivery, it shall be the responsibility of the contractor to notify in writing the Division of Purchase and Contract at once, indicating the specific regulation which required such alterations. The State reserves the right to accept any such alterations, including any price adjustments occasioned thereby, or to cancel the contract.
 3. **AVAILABILITY OF FUNDS:** Any and all payments to the contractor are dependent upon and subject to the availability of funds to the agency for the purpose set forth in this agreement.
 4. **TAXES:** Any applicable taxes shall be invoiced as a separate item.
 5. **SITUS:** The place of this contract, its situs and forum, shall be North Carolina, where all matters, whether sounding in contract or tort, relating to its validity, construction, interpretation and enforcement shall be determined.
 6. **GOVERNING LAWS:** This contract is made under and shall be governed by and construed in accordance with the laws of the State of North Carolina.
 7. **INSPECTION AT CONTRACTOR'S SITE:** The State reserves the right to inspect, at a reasonable time, the equipment/item, plant or other facilities of a prospective contractor prior to contract award, and during the contract term as necessary for the State's determination that such equipment/item, plant or other facilities conform with the specifications/requirements and are adequate and suitable for the proper and effective performance of the contract.
 8. **PAYMENT TERMS:** Payment terms are Net, 30 days after receipt of correct invoice or acceptance of goods, whichever is later. The using agency is responsible for all payments under the contract.
- AFFIRMATIVE ACTION:** The contractor will take affirmative action in complying with all Federal and State requirements concerning fair employment and employment of the handicapped, and concerning the treatment of all employees, without regard to discrimination by reason of race, color, religion, sex, national origin or physical handicap.
10. **CONDITION AND PACKAGING:** Unless otherwise provided by special terms and conditions or specifications, it is understood and agreed that any item offered or shipped has not been sold or used for any purpose and shall be in first class condition. All containers/packaging shall be suitable for handling, storage or shipment.
 11. **STANDARDS:** All manufactured items and/or fabricated assemblies subject to operation under pressure, operation by connection to an electric source, or operation involving a connection to a manufactured, natural, or LP gas source shall be constructed and approved in a manner acceptable to the appropriate state inspector which customarily requires the label or re-examination listing or identification marking of the appropriate safety standard organization: such as the American Society of Mechanical Engineers for pressure vessels; the Underwriters Laboratories and/or National Electrical Manufacturers' Association for electrically operated assemblies; or the American Gas Association for gas operated assemblies, where such approvals of listings have been established for the type of device offered and furnished. Further, all items furnished shall meet all requirements of the Occupational Safety and Health Act (OSHA), and state and federal requirements relating to clean air and water pollution.
 12. **PATENT:** The contractor shall hold and save the State, its officers, agents and employees, harmless from liability of any kind, including costs and expenses, on account of any copyrighted material, patented or unpatented invention, articles, device or appliance manufactured or used in the performance of this contract, including use by the government.
 13. **ADVERTISING:** Contractor agrees not to use the existence of this contract or the name of the State of North Carolina as a part of any commercial advertising without prior approval of the Division of Purchase and Contract.
 14. **ACCESS TO PERSONS AND RECORDS:** The State Auditor shall have access to persons and records as a result of all contracts or grants entered into by State agencies or political subdivisions in accordance with General Statute 147-64.7.
 15. **ASSIGNMENT:** No assignment of the contractor's obligations nor the contractor's right to receive payment hereunder shall be permitted. However, upon written request approved by the Division of Purchase and Contract and solely as a convenience to the contractor, the State may:
 - a. forward the contractor's payment check directly to any person or entity designated by the contractor, and
 - b. include any person or entity designated by contractor as a joint payee on the contractor's payment check..
- In no event shall such approval and action obligate the State to anyone other than the contractor and the contractor shall remain responsible for fulfillment of all contract obligations.



BID No. 501623

BIDDER: _____

16. INSURANCE:

COVERAGE - During the term of the contract, the contractor at its sole cost and expense shall provide commercial insurance of such type and with such terms and limits as may be reasonably associated with the contract. As a minimum, the contractor shall provide and maintain the following coverage and limits:

- a. **Worker's Compensation** - The contractor shall provide and maintain Worker's Compensation Insurance, as required by the laws of North Carolina, as well as employer's liability coverage with minimum limits of \$150,000.00, covering all of contractor's employees who are engaged in any work under the contract. If any work is sublet, the contractor shall require the subcontractor to provide the same coverage for any of his employees engaged in any work under the contract.
- b. **Commercial General Liability** - General Liability Coverage, on a Comprehensive Broad Form on an occurrence basis in the minimum amount of \$500,000.00 Combined Single Limit. (Defense cost shall be in excess of the limit of liability.)
- c. **Automobile** - Automobile Liability Insurance, to include liability coverage, covering all owned, hired and non-owned vehicles, used in connection with the contract. The minimum combined single limit shall be \$150,000.00 bodily injury and property damage; \$150,000.00 uninsured/under-insured motorist; and \$1,000.00 medical payment.

REQUIREMENTS: Providing and maintaining adequate insurance coverage is a material obligation of the contractor and is of the essence of this contract. All such insurance shall meet all laws of the State of North Carolina. Such insurance coverage shall be obtained from companies that are authorized to provide such coverage and that are authorized by the Commissioner of Insurance to do business in North Carolina. The contractor shall at all times comply with the terms of such insurance policies, and all requirements of the insurer under any of such insurance policies, except as they may conflict with existing North Carolina laws or this contract. The limits of coverage under each insurance policy maintained by the contractor shall not be interpreted as limiting the contractor's liability and obligations under the contract.

17. **CANCELLATION (TERM CONTRACTS ONLY):** All contract obligations shall prevail for at least 180 days after effective date of the contract. After that period, in addition to the provisions of the paragraph entitled Price Adjustments, for the protection of both parties, this contract may be canceled in whole or in part by either party by giving 30 days prior notice in writing to the other party.

Such notice of cancellation, as required herein, shall be transmitted VIA U.S. MAIL, Certified, Return-Receipt Requested. The 30 days notice for cancellation shall begin on the day the return receipt is signed and dated.

QUANTITIES (TERM CONTRACTS ONLY): The award of a term contract neither implies nor guarantees any minimum or maximum purchases thereunder.

19. **PRICE ADJUSTMENTS (TERM CONTRACTS ONLY):** Any price changes, downward or upward, which might be permitted during the contract period must be general, either by reason of market change or on the part of the contractor to other customers.

- a. **Notification:** Must be given to the Division of Purchase and Contract, in writing, concerning any proposed price adjustments. Such notification shall be accompanied by copy of manufacturer's official notice or other acceptable evidence that the change is general in nature.
- b. **Decreases:** The State shall receive full proportionate benefit immediately at any time during the contract period.
- c. **Increases:** All prices shall be firm against any increase for 180 days from effective date of the contract. After this period, a request for increase may be submitted with the State reserving the right to accept or reject the increase, or cancel the contract. Such action by the State shall occur not later than 15 days after receipt by the State of a properly documented request for price increase. Any increases accepted shall become effective on a date to be determined by the State which:
 - 1) Shall not be later than 30 days after the expiration of the original 15 days reserved by the State to evaluate the request for increase; and
 - 2) Which date coincides with the State's next scheduled distribution of Contract Addenda to the various using agencies throughout the State. These distributions occur approximately every four weeks.)
- d. **Invoices:** It is understood and agreed that orders will be shipped at the established contract prices in effect on dates orders are placed. Invoicing at variance with this provision will subject the contract to cancellation. Applicable North Carolina sales tax shall be invoiced as a separate item.